THESIS/
REPORTS
ANDERSON,
E.B.

TECHNICAL SUPPORT
ON
THE AERIAL DELIVERY PROGRAM
FINAL SUMMARY REPORT
INT GRANT No. 9

Submitted to

THE AEROSPACE CORPORATION

TECHNICAL SUPPORT
ON
THE AERIAL DELIVERY PROGRAM
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INT GRANT No. 9

Submitted to

USDA - Forest Service

Intermountain Forest and Range Experiment Station

Missoula, Montana 59801

January, 1976

Submitted by

Energy and Transportation Division
Natural Resources Group
The Aerospace Corporation
P. O. Box 92957
Los Angeles, California 90009

TECHNICAL SUPPORT ON
THE AERIAL DELIVERY PROGRAM
FINAL SUMMARY REPORT
INT GRANT #9
USDA - FOREST SERVICE
NORTHERN FOREST FIRE LABORATORY
INTERMOUNTAIN FOREST AND RANGE
EXPERIMENT STATION
MISSOULA, MONTANA, 59801

Submitted by Earl B. Anderson

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INTRODUCTION

The Aerospace Corporation has been supporting the Aerial Delivery Research Program at the Northern Forest Fire Laboratory (NFFL) for several years. In December 1972 Aerospace began support on the initial phases of this program by developing Program Plans, Technical Statements of Work, and conducting technical studies associated with the dispersion of retardant from aircraft (e.g., computerized modeling of retardant drops.) Another major output of that effort was the development of a mathematical model for determining a preferred pre-fire deployment of air tankers near high fire hazard locations based on an expected least total cost (damage and operating) criteria. As a continuation of the earlier effort, INT Grant No. 9 was received by Aerospace to provide technical support to the Forest Service on the Experimental Tank and Gating System ETAGS test phase of the Aerial Delivery Research Program. This report is a summary of the Aerospace effort on the specific tasks covered in this grant.

TECHNICAL TASKS

The technical support provided to the NFFL as part of this grant included; technical evaluation of proposals, review of the design and structural analysis of the proposed tank and gating system, analysis of the contractors proposed instrumentation for the bench, ground and flight tests, and a review of the contractors test program. All of the above items were examined for feasibility, conformity to specifications, and contractual compliance. Letter reports were submitted to the NFFL containing Aerospace findings and recommendations as each of the above items were completed. A review of each task follows.

ETAGS Program Proposal Reviews - On 28 through 31 May 1974 Aerospace Personnel W. E. Ellis, R. Hanson and H. Dykstra supported the technical evaluation of proposals submitted in response to Request for Proposals (RFP R1-74-85) (Ref. 1) on the Experimental Tank and Gating System (Ref. 2). This evaluation was held at the NFFL, Missoula, Montana. A total of 3 proposals were evaluated and written comments on each of these

were submitted to the Forest Service. Prior to the evaluation background documents on the entire Aerial Delivery Program were reviewed to assure consideration of the history leading to the ETAGS Program in the technical evaluation.

Design and Structural Analysis Review of the Honeywell Experimental Tank and Gating System - On 13-14 November 1974, E. Anderson and Dr. R. Carter of Aerospace Corporation visited the NFFL to attend a design review of the Honeywell ETAGS system. At that time, Honeywell had not completed the structural design or analysis, however, in discussions held with the contractor agreements were reached on the load limits for design purposes (Ref. 3). A basic understanding of the design concept was also obtained and no extensive deviation from the RFP requirements or the proposal (Ref. 4) submitted by Honeywell were envisioned.

On February 3, 1975 drawings of the ETAGS system and a final stress analysis were received at Aerospace from Honeywell.

Three drawings were received from Honeywell:

Experimental Tank and Gating System - Structure
Drawing No. 28110188 - 6 sheets
Experimental Tank and Gating System - Doors
Drawings No. 28110417 - 4 sheets
Schematic Diagram, Hydraulic System, ETAGS
Drawing No. 28110698 - 1 sheet

A review of these drawings for conformance to the Statement of Work in the RFP and agreement with the Honeywell proposal revealed no significant deviations. Tank volumes and door openings were adequate as shown (Figures 1 - 4). Clutter was minimized within the core of the tank. A major advantage of the design was the fact that attachment to the P2-V was at the same locations as the operational tank and as such no major modifications were required to the aircraft structure. There were several comments on the Honeywell stress analysis (Appendix 1) forwarded (Ref. 5) which are repeated below.

PART NO.

REVISIONS				
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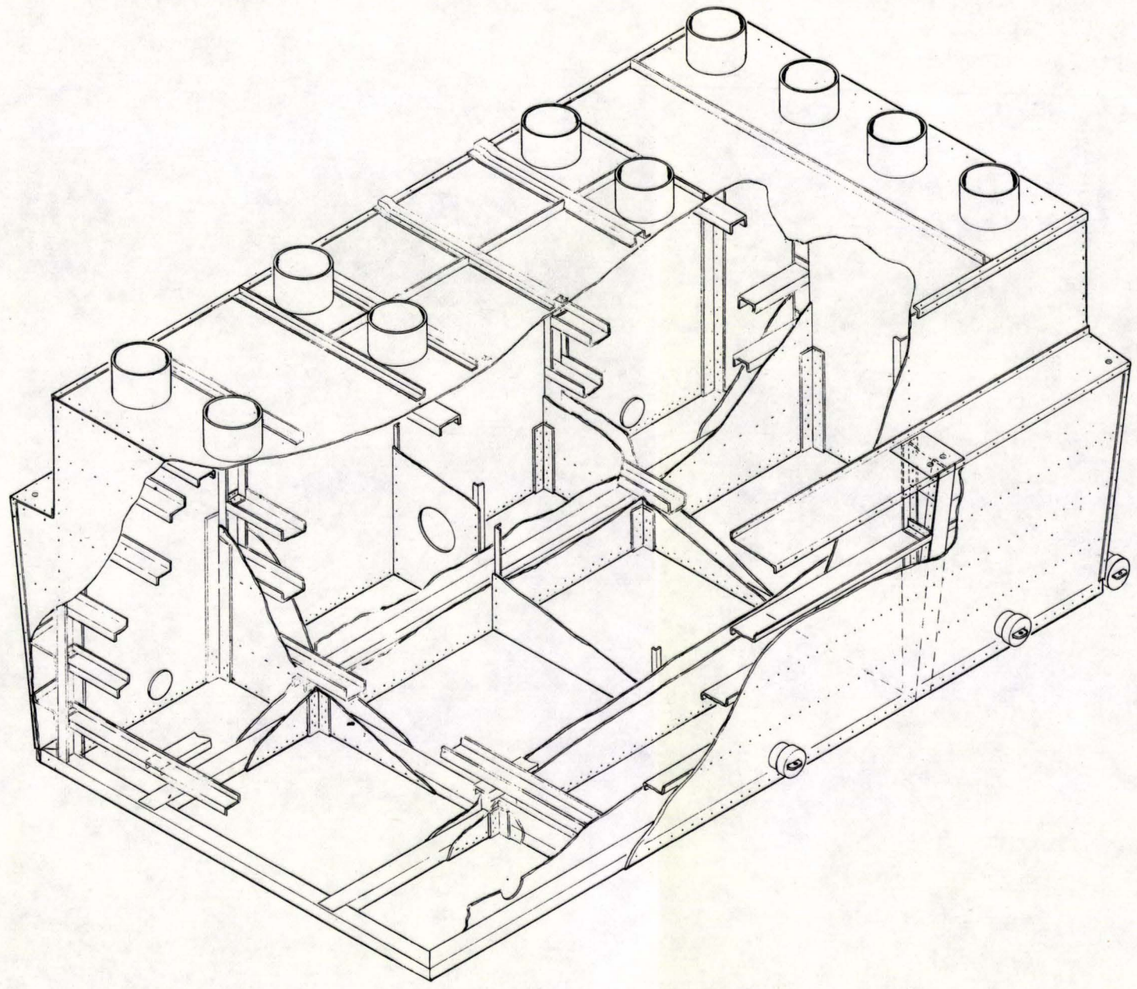

NOTES:

1 - EDGE DISTANCE FOR RIVETS AND OTHER FASTENERS TO BE 2 X DIA +.06.

2 - RIVETS ARE TO BE 5/32 DIA UNLESS OTHERWISE SPECIFIED. RIVETS ARE TO BE OF THE FOLLOWING TYPES:

(A) RIVET, SOLID-UNIVERSAL HEAD MS20470AD5 ALUMINUM ALLOY 2117.

(B) RIVET-BLIND, PROTRUDING HEAD, LOCKED SPINDLE ALUMINUM ALLOY,. 2017 NAS 1398D5.

(C) RIVET-BLIND 100° FLUSH HEAD LOCKED SPINDLE ALUMINUM ALLOY, 2017 NAS 1399D5.

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.X ±
.XX ±
.XXX ±

90° FORMED ANGLES +2° -1°

DRAFTSMAN 11-15-74
CHECKER
DEV ENGR
ENG/RG MGT

MATERIAL

CONTRACT NO.

REFERENCE	APPLICATION		FINISH-SEE NOTE
	NEXT ASSY	USED ON	

HONEYWELL INC.

GOVERNMENT AND AERONAUTICAL PRODUCTS DIVISION
2600 RIDGWAY PARKWAY
MINNEAPOLIS, MINNESOTA 55413

EXPERIMENTAL TANK AND GATING SYSTEM-STRUCTURE

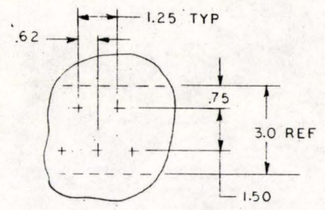
SIZE	CODE IDENT NO.	DRAWING NO.
F	94580	28110188

SCALE 1/10 SHEET 1 OF 6

DWG NO. 28110188 REV A

PART NO.

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APP'D



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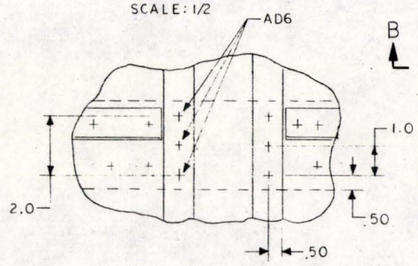

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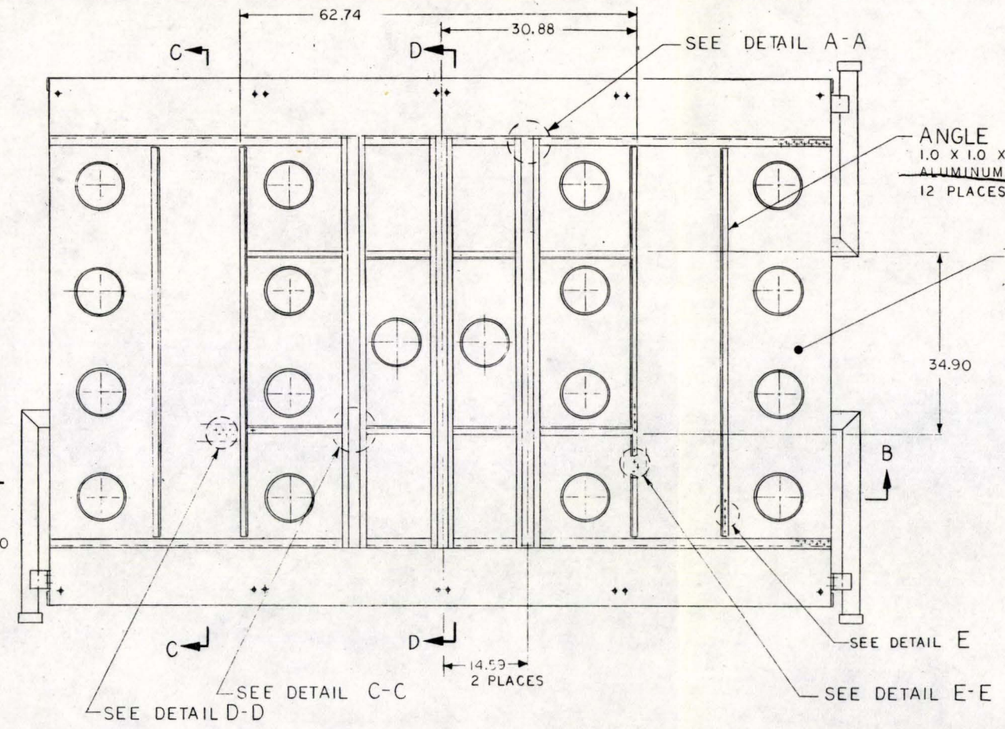

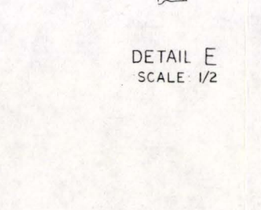

DETAIL E
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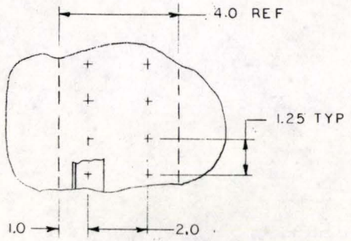

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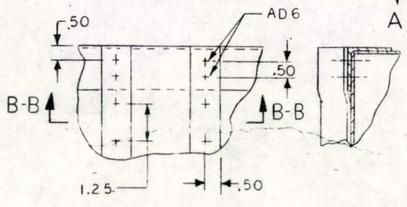

DETAIL A-A
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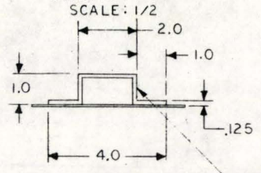

SECTION B-B
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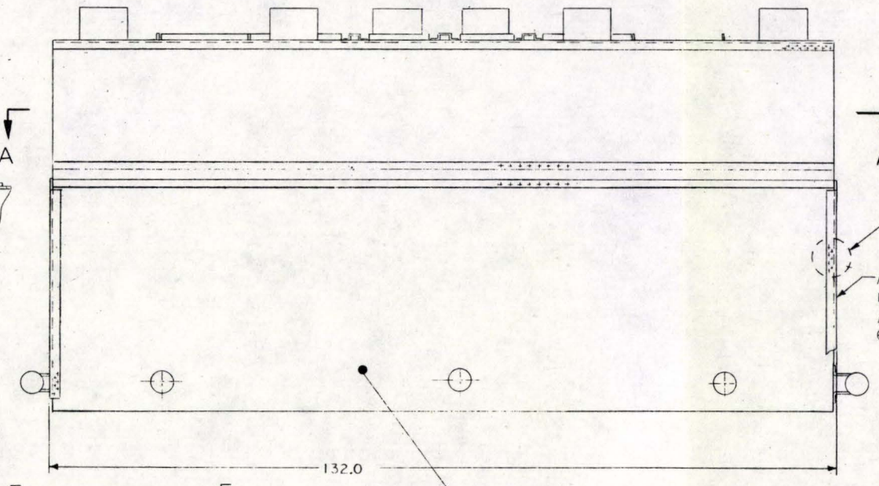
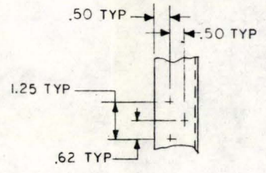


HAT SECTION
ALUMINUM 6061-T6
3 PLACES

SIDE SKIN
.063 THICK
ALUMINUM 6061-T6
4 PLACES



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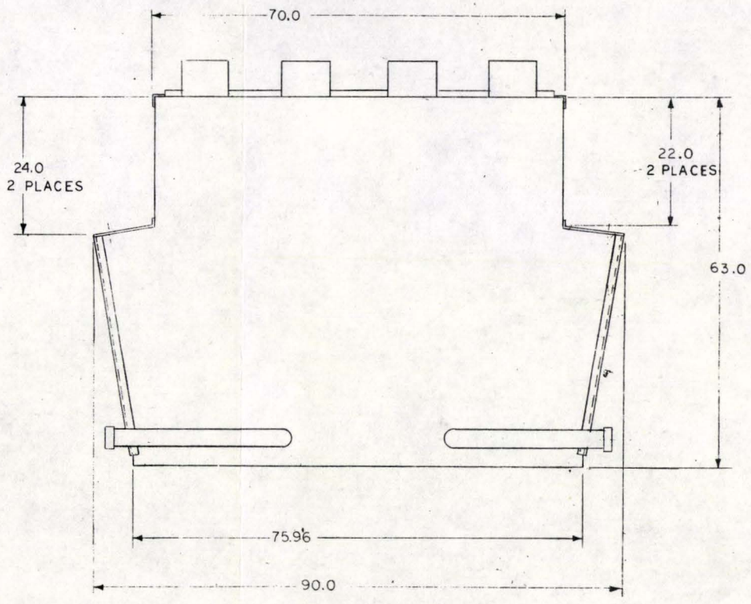

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TOLERANCES UNLESS NOTED OTHERWISE
X ±
.XX ±
.XXX ±
90° FORMED ANGLES +00 -10

DRAFTSMAN	Dahlman	11-11-74
CHECKER		
DEV ENGR		
ENGRG MGT		

MATERIAL

CONTRACT NO.

REFERENCE	NEXT ASSY	USED ON

FINISH-SEE NOTE

HONEYWELL INC.
GOVERNMENT AND AERONAUTICAL PRODUCTS DIVISION
2600 RIDGWAY PARKWAY
MINNEAPOLIS, MINNESOTA 55413

EXPERIMENTAL TANK AND GATING SYSTEM-STRUCTURE

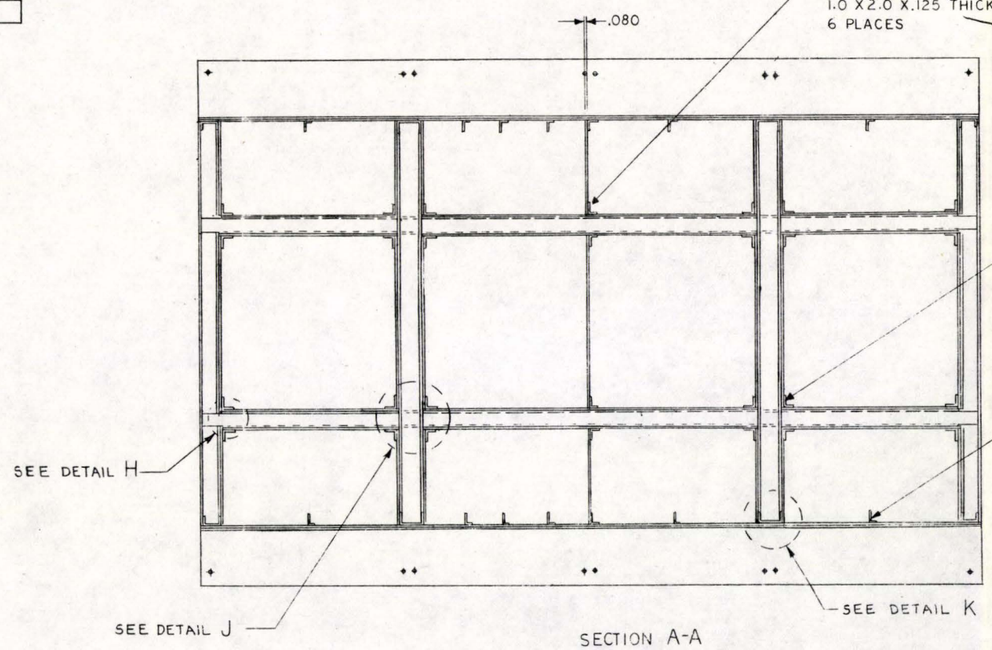
SIZE	CODE IDENT NO.	DRAWING NO.
F	94580	28110188

SCALE 1/10 SHEET 2 OF 6

DWG NO. 28110188 REV

PART NO.

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED



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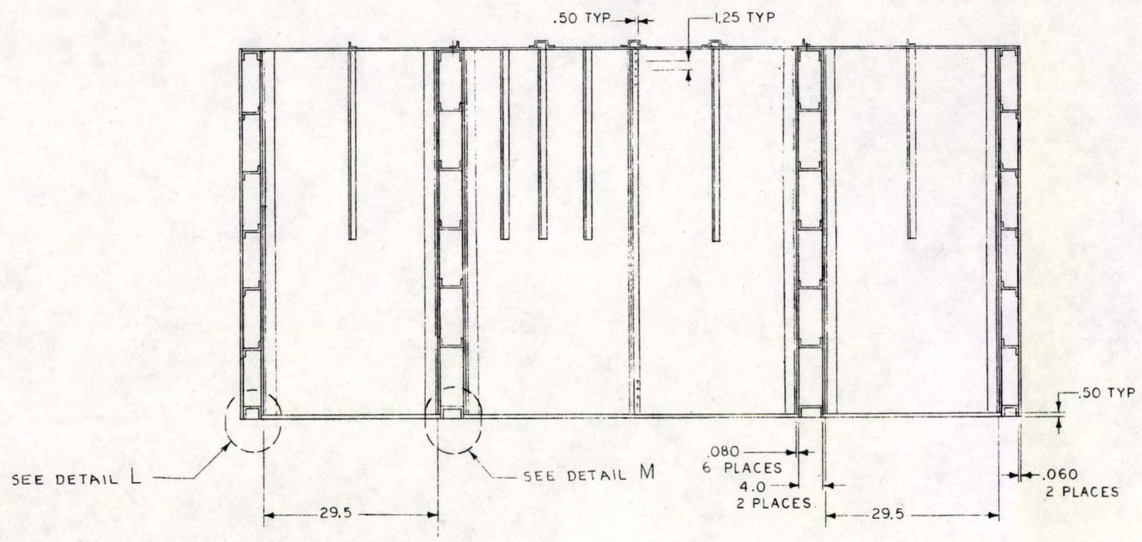

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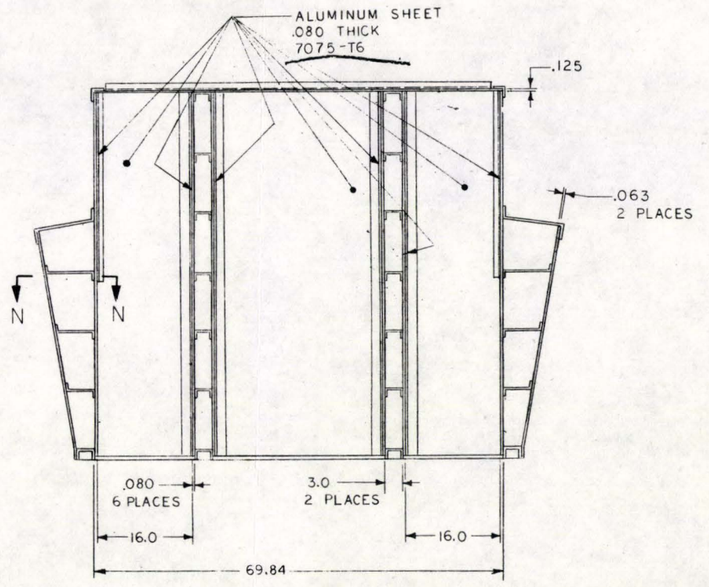

SECTION C-C

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.XX ±
.XXX ±
90° FORMED ANGLES ±2° ±0
MATERIAL
FINISH-SEE NOTE

REFERENCE	NEXT ASSY	USED ON

DRAFTSMAN 11-11-74
CHECKER
DEV ENGR
ENGRG MGT
CONTRACT NO.

HONEYWELL INC.
GOVERNMENT AND AERONAUTICAL PRODUCTS DIVISION
2600 RIDGWAY PARKWAY
MINNEAPOLIS, MINNESOTA 55413

EXPERIMENTAL TANK AND GATING SYSTEM-STRUCTURE

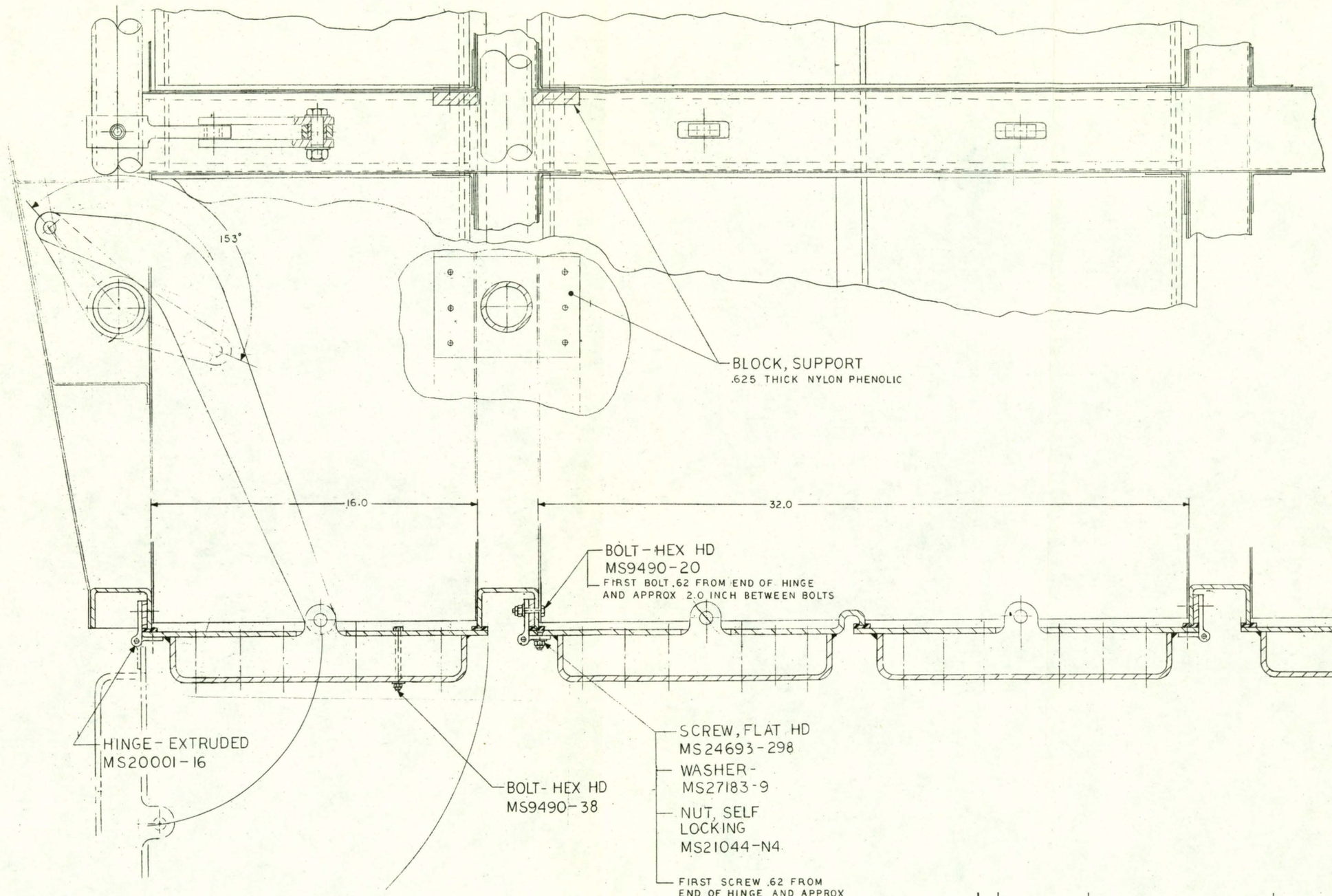
SIZE	CODE IDENT NO.	DRAWING NO.
F	94580	28110188

SCALE 1/10 SHEET 3 OF 6

DWG NO. 28110188 REV B

PART NO.

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED



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TOLERANCES UNLESS NOTED OTHERWISE
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.XX ±
.XXX ±
90° FORMED ANGLES ±2°
.1°

MATERIAL

FINISH-SEE NOTE

REFERENCE	NEXT ASSY	USED ON

DRAFTSMAN 11-14-74
CHECKER
DEV ENGR
ENGRG MGT

CONTRACT NO.

HONEYWELL INC.

GOVERNMENT AND AERONAUTICAL PRODUCTS DIVISION
2600 RIDGWAY PARKWAY
MINNEAPOLIS, MINNESOTA 55413

EXPERIMENTAL TANK AND GATING SYSTEM - DOORS

SIZE	CODE IDENT NO.	DRAWING NO.
F	94580	28110417

SCALE 1/2 SHEET 1 OF 4

28110417

The contractor designed and analyzed the tank for the following loading conditions:

Limit Inertia Loading

A. 3g fwd, 1g down

B. ± 1.5g lateral 1g down

C. 1g up

D. 3g down.

Limit Internal Pressure Loading (Center Compartment Only)

E. when full, 3 psi plus 1g down

F. when empty, 5.4 psi plus 1g down.

Ultimate load factors of safety of 1.5 for inertia loads and 2.0 for pressure were used. These loading conditions and factors of safety conformed with agreements made during the November design review. Not considered in the analysis, however, were door deployment loads and air loads on deployed doors. The contractor had indicated that these two conditions would be considered.

The stress analysis and structural design were reviewed in detail and were found to be generally good. With a few exceptions the analysis was comprehensive and satisfactorily demonstrated that the design met the requirements. Table 1 summarizes the minimum margins of safety computed for the individual parts of the structure. All margins of safety were greater than zero which indicated that the structural elements were capable of sustaining a larger load than required. (Margin of safety is defined as M.S. = 1/R - 1 where R is the ratio of applied stress to the allowable stress).

In addition to the omission of air and deployment loads, there were a few other questionable aspects of the analysis which could affect the design. The four aircraft attachment fittings at the ends of the tank were not analyzed in sufficient detail. The eccentric loading on these fittings was not considered, and this eccentricity could significantly degrade the load capability of the attachment. The strength capability predictions of the other

Table 1 - Summary of Minimum Margins of Safety Computed by Honeywell

	Structural Element	M.S.	Load Condition	Failure Mode
1.	Skin of Double Walls	0.24	A	Material Failure at Ultimate Load
2.	Upper External Skin of Sides	0.94	A	Material Failure at Ultimate Load
3.	Top Skin	0.86	C	Material Failure at Ultimate Load
4.	Stiffeners of Fwd, Aft, and Longitudinal Bhds.	0.15	A	Material Failure at Ultimate Load
5.	Channel Stiffeners for Intermediate Transverse Bhds	0.08	A	Material Failure at Utlimate Load
6.	Connection of Longitudinal and Intermediate Trans. Bhds.	0.02	F	Rivet Failure at Ultimate Load
7.	Connection of Trans. Bhds.	0.02	F	Rivet Failure at Ultimate Load
8.	Vertical Angles on Side Skin	0.73	A	Material Failure at Ultimate Load
9.	Horizontal Hat Stiffeners on Top Skin	0.16	F	Material Failure at Ultimate Load
10.	Deployable Door	0.01	D	Local Bending Failure at Hinge Conn.
11.	Four Single Bolt Connections at Tank Ends	0.28	D	Shear Buckling of Web
12.	Double Bolt Connections at Intermediate Supports	0.42	D	Ultimate Strength of "T" Clip

six attachments was questionable. Although the contractor's analysis of these attachments indicated that these will provide the necessary support, design data other than that used by Honeywell indicated that these attachments were not strong enough.

The contractor determined deflections of the deployable doors that result from the most severe load case - Condition D. The calculated peak deflection at the edge of the door is 0.059 in. and 0.088 in. for limit and ultimate loads, respectively. This seems like an acceptable deflection for the 0.187 in. thick neoprene rubber gasket, but the contractor did not state an allowable deflection. Moreover, Honeywell did not consider the door deflection resulting from deformation of the support arms which could be important.

The above comments and some design and analytical details were discussed with G. Johnson of Honeywell on February 13. He agreed to:

1. Address door air loads and deployment loads
2. Analyze the four end attachments to the aircraft considering eccentric loading and to make any necessary design changes.
3. Increase the thickness of the T member at the six intermediate aircraft attachments from 0.25 in. to 0.375 in. (This will provide ample strength.)
4. Investigate corrosion control of steel bolts used in various joints of the tank.
5. Determine allowable door deflections.
6. Determine the preload in door support arms and determine the amount of door deflection resulting from stresses in the support arms when subjected to critical loading conditions.
7. Determine rivet spacing in skin to channel joint of section U-U of tank drawings.
8. Investigate rivet and bolt spacing in details L and M of the tank drawings.

Later discussions with Honeywell ascertained that the changes required were made and the structural integrity of the tank and gating system was deemed adequate.

Instrumentation Review - On August 4-6, 1975, E. Anderson and R. Hanson visited Honeywell, Hopkins, Minnesota for the purpose of reviewing the instrumentation to be used on the ETAGS throughout the bench, ground and flight test program. At the time of our visit all of the instrumentation had not been installed on the ETAGS, but the proposed instrumentation design was available and reviewed. The instrumentation system is described below.

An instrumentation power supply provides excitation to potentiometers, pressure transducers, and an accelerometer. The outputs from these transducers frequency modulate voltage controlled oscillators in the tape recorder. Each data track on the magnetic tape has one transducer output; there is no multiplexing. Since the number of transducers outputs exceeded the number of tracks available on the tape recorder, a patch panel allowed the selection of the desired transducers for each test. The transducers to monitor the tank flow rate are not commercially available and were designed and fabricated by Honeywell.

A Honeywell, Model 5600, portable tape recorder is used in the aircraft to record the desired signals on 14 tracks using frequency modulation. The magnetic tape is played back for a "quick look" to determine data quality before shipping the tapes to Honeywell in Minneapolis for a complete data analysis. In the field, the magnetic tape recorder output will be displayed by direct writing pen recorders. This was considered an important feature because it allowed immediate remedial action to be taken to correct any anomalies in the instrumentation before the next flight test.

A block diagram of the system is shown in Figure 5. Major Components of the system are as follows:

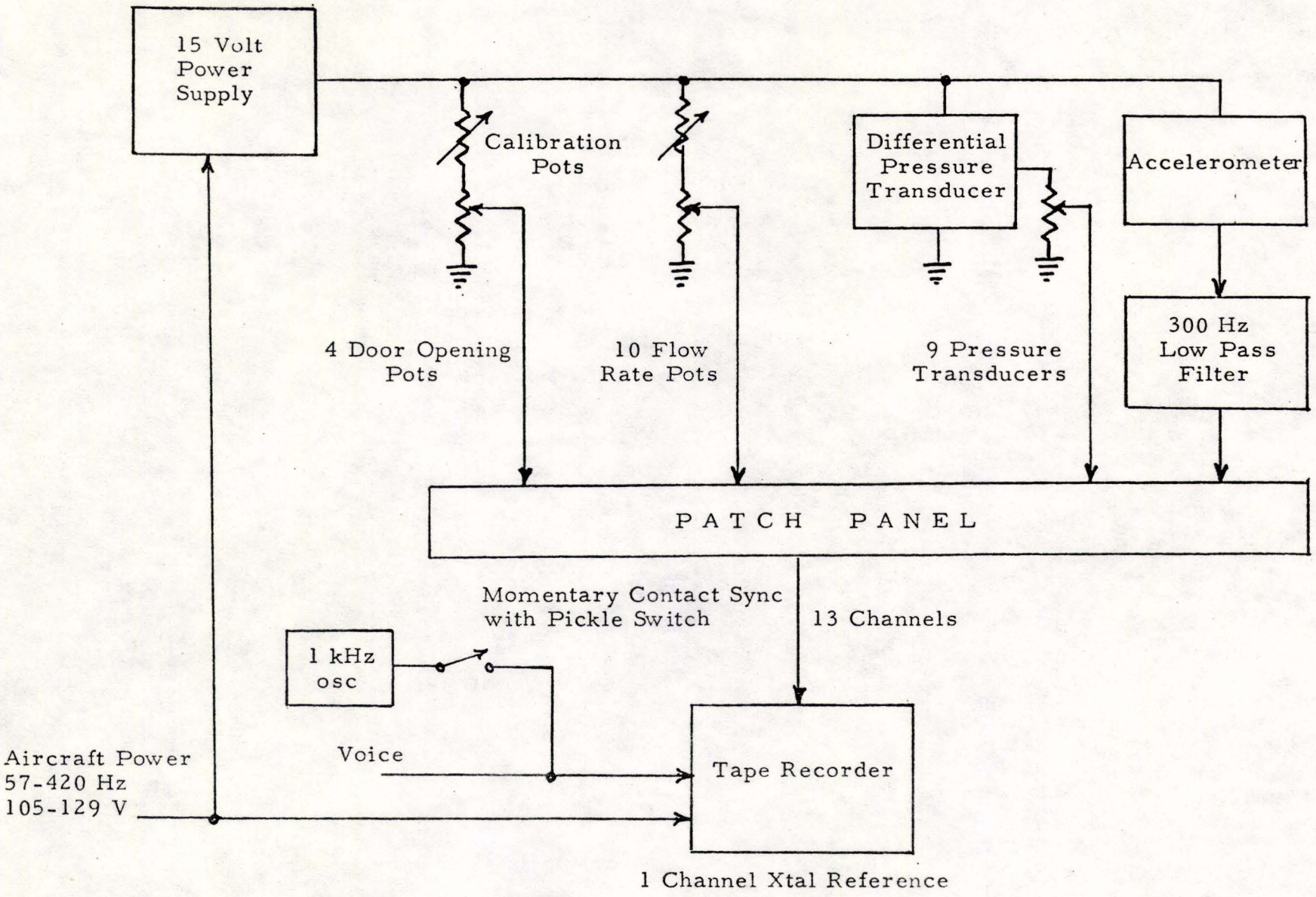

FIGURE 5

ETAGS INSTRUMENTATION BLOCK DIAGRAM

Excitation Power Supply

Make and Model:	Lambda LXS-A-15
Input:	105 to 132 VAC, 47 to 440 Hz
Output Voltage:	15 volts adjustable to ± 5%
Output Current:	Maximum ranges from 2.4 amps at 40°C to 1.3 amps at 71°C
Regulation:	0.1% with input variations from 105 to 132 volts and no load to full load
Ripple:	5 millivolts peak-to-peak

Liquid Level Potentiometers

Make and Model:	Bourns-3501, 10 turn helipot
Part Number:	35015-1-102
Resistance:	1,000 ohms
Linearity:	± 0.5%

Door Position Potentiometers

Make and Model:	Spectrol-152, bushing mount
Resistance:	1,000 ohms
Linearity:	± 0.5%

Pressure Transducers

Make and Model:	National Semiconductor LX 1701D
Pressure Range:	-5 to +5 psi differential
Linearity and Hysteresis:	± 0.5%
Output Voltage:	2.5 to 12.5 volts

Accelerometer

Make and Model:	PCB-308A02
Sensitivity:	1 volt/g
Frequency Range:	1 to 3000 Hz

Tape Recorder

Make and Model:	Honeywell 5600
Number of Channels:	14
Tape Width:	1 inch
Maximum Reel Diameter	10 1/2 inch
Tape Speed:	3 3/4 ips
Flutter:	0.7% 2 cumulative over bandwidth of 0.2 to 625 Hz
Electronics:	Extended Intermediate Band FM ± 40% Deviation
S/N:	40 dB
Data Bandwidth:	DC to 1.25 kHz
Linearity:	± 1%
Drift:	1% of full deviation
Note:	One direct record/reproduce electronics needed for servo reference channel

In general the instrumentation was acceptable, adequately covered the Statement of Work requirements and was consistent with the Honeywell proposal. We reported the following concerns (Ref. 6 and 7).

Honeywell had re-designed the door opening crank mechanism which resulted in reducing the door opening angle from between 85° and 90° to 71°. Although, tank configurational variations could be studied with a 71° door opening, we recommended that Honeywell proceed with a re-design of the crank to achieve as close to a 90° door opening as possible. This would eliminate later questioning of the test results and be in keeping with the original plans for a "clean" tank and "full" door opening. Another recommendation was to use one channel of tape for a crystal controlled time pulse which was assigned in the original plans but not mechanized. Other improvements were suggested to improve the quality of the data.

Liquid Level Transducer - A redesign to provide positive guidance of the float over the limits of travel without interference with the pulleys was

suggested. It was recommended that the clearance between the float and guide wire be increased to prevent viscous drag and the float travel limits be increased to permit measuring zero and full tank conditions. It was thought desirable to get the helipot out of the liquid, thus reducing the sealing problems. It was also suggested that the series calibration pots be mounted in an accessible place, be provided with locking devices to maintain adjustment under aircraft vibration and the pot be adjusted to provide zero volts output at zero liquid level. The float travel of about 4 1/4 turns of the helipot provides an acceptable resolution.

Event Signal - The use of a dc level on the voice track to indicate the closing of the pickle switch was not desirable. Two alternative designs were suggested. (1) A short burst from a simple 1 kHz oscillator could be recorded on the voice track at the switch closing time. (2) a "blip" generated from a capacitor discharge could be used to deviate one of the FM channels. The time constants should be chosen so that the blip has disappeared before the other data begins.

Reference Channel - As was indicated in the test plan channel assignments, one channel should be devoted to recording a crystal-controlled reference signal to assure that the playback will be held at the same tape speed as the recording and minimize effects of differences in capstan speeds, tape dimensional changes, and low frequency flutter. Both the Honeywell 5600 and the 7610 have this capability. Accurate determination of time is possible by counting the cycles on this reference track.

FM Deviation - It was suggested that the full $\pm$ 40% deviation of each FM channel be used rather than one-half from zero to +40% as now planned to reduce the effects of noise flutter and drift. This could be accomplished by offsetting the FM carrier so that zero volts input corresponds to -40% deviation.

Door Opening Potentiometers - The selection of the pots for the door positions was acceptable. Since these were not installed nor prints available, no specific comments were made. The disadvantage of attaching the pots

to the torque tubes rather than to the doors is the non-linear relation between the motion of the two requiring a calibration curve for data analysis in the field. No problem for data reduction by computer at Honeywell was anticipated.

Tape Recorder - The Honeywell Model 5600 portable tape recorder should have provisions for recording voice on an edge track and for recording a crystal reference signal on any track for tape servo lock. Provisions should be included to play back tapes in the field for quick look checks using the tape servo lock. The number of play-back channels need only match the number of direct writing channels available if patching is provided to select any of the tracks.

Test Program Review - The test matrix for the flight test program (Appendix II) was reviewed at Aerospace for conformance to the work statement requirements and for adequacy to obtain data for validation of the Honeywell drop pattern computer model. The following comments were provided (Ref. 8).

The Honeywell documentation showed a series of twelve test designations which included variations to learn the effects of aircraft velocity, drop height, door opening rate, tank and exit geometry, retardant volume and provisions for rheological testing through repetitive tests at certain configurations.

The complete set of options selected by Honeywell would provide the data variations required to check out their drop pattern computer program. One inconsistency was noted. In test series XI and XII (door area opening variations) it was not clear whether a 500 gal. or 1000 gal. drop is to be used. The illustration indicated the former while the data channel list indicated the latter. Since a majority of the variables are studied through variations of the standard tank, we recommended that the 1000 gal. configuration be preferred. If time and money would permit, both volumes should be studied.

On November 17, 1975, E. Anderson visited the flight test site at Chico, California for the purpose of reviewing the contractors compliance

with program requirements during the test phase. The instrumentation installed on the P2-V was essentially as described earlier and for the most part was operating satisfactorily. Some problems such as contamination of the float gauge pulleys and whipping of the float gauge guide wires after tank evacuation did occur, however sufficient tank flow data was obtained to enable the contractor to exercise their computerized drop pattern model. Some contractual problems did arise which were discussed at Chico and Aerospace recommendations concerning the contractors responsibility to complete the test phase were forwarded (Ref. 9).

REFERENCES

1.0 Research and Service Contract - U.S. Dept of Agriculture, Forest Service, Federal Building, Missoula, Montana 59801, (RFP R1-74-85)

2.0 Aerospace Letter Progress Report #1 - P. M. Stevens to C. W. George, August 13, 1974

3.0 Aerospace Letter, E. B. Anderson to C. W. George, December 3, 1974

4.0 Experimental Tank and Gating System Proposal, Government and Aeronautical Products Division, Honeywell, Hopkins, Minn. 55343, May 24, 1974

5.0 Aerospace Letter Progress Report #2 - P. M. Stevens to C. W. George, March 10, 1975

6.0 Aerospace Letter, E. B. Anderson to C. W. George, August 8, 1975

7.0 Aerospace Letter, E. B. Anderson to C. W. George, August 14, 1975

8.0 Aerospace Letter, E. B. Anderson to C. W. George, September 3, 1975

9.0 Aerospace Letter, E. B. Anderson to C. W. George, December 1, 1975.

APPENDIX I

HONEYWELL STRUCTURAL ANALYSIS

STRUCTURAL ANALYSIS

OF THE

EXPERIMENTAL TANK & GATING SYSTEM

GORDON R. JOHNSON

JANUARY 30, 1975

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STRUCTURAL ANALYSIS

AEROSPACE & DEFENSE GROUP
GOVERNMENT & AEROSPACE PRODUCTS DIVISION

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INERTIAL LOADING CONDITIONS

- COND A

$n_x = -3.0$ g's (FORWARD)
$n_z = -1.0$ g's (DOWN)

- COND B

$n_y = \pm 1.5$ g's (LATERAL)
$n_z = -1.0$ g's (DOWN)

- COND C

$n_z = 1.0$ g's (UP)

- COND D

$n_z = -3.0$ g's (DOWN)

INTERNAL PRESSURE LOADING CONDITIONS

(CENTER COMPARTMENT ONLY)

- COND E

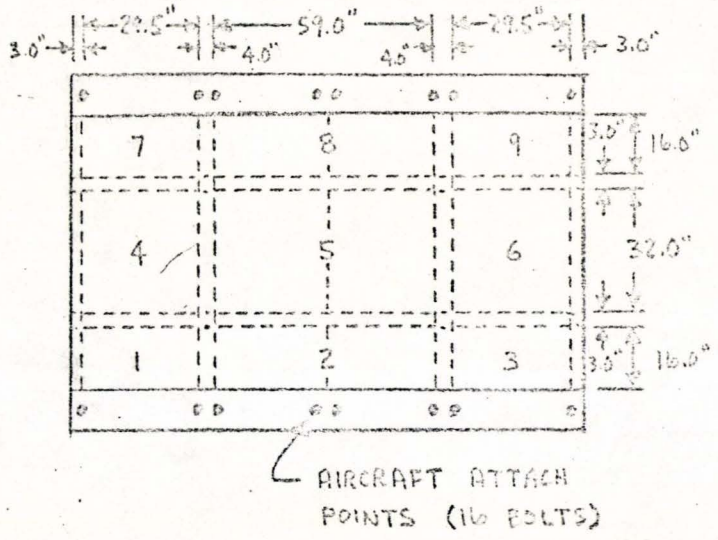
P = 3.0 PSI (FULL CENTER COMPARTMENT)
$n_z = -1.0$ g's (DOWN)

- COND F

P = 5.4 PSI (EMPTY CENTER COMPARTMENT)
$n_z = -1.0$ g's (DOWN)

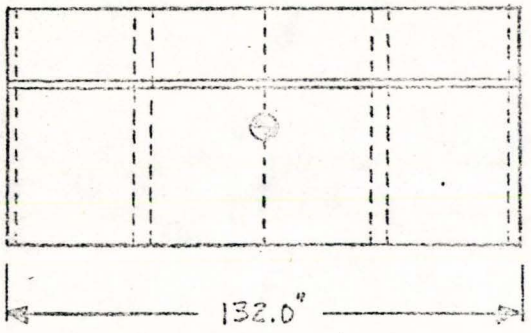
NOTES:

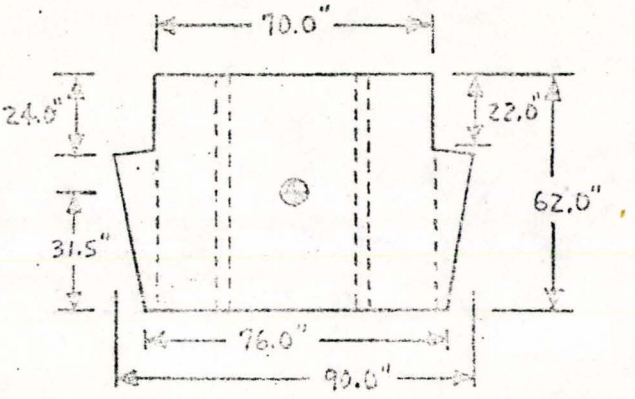
- COND A-F ARE LIMIT LOADING CONDITIONS
- THE ULTIMATE FACTOR OF SAFETY FOR THE INERTIAL LOADS IS 1.5
- THE ULTIMATE FACTOR OF SAFETY FOR THE PRESSURE LOADS IS 2.0
- COND A-F ARE CONSIDERED INDEPENDENTLY



WEIGHT DISTRIBUTION

EMPTY TANK	=	2,500 LBS
RETARDANT	=	20,000
TOTAL WT	=	22,500 LBS





CALCULATE RETARDANT WEIGHT FOR VARIOUS COMPARTMENTS

RETARDANT DENSITY = 10 LBS/GAL = .0433 LBS/IN^3
RETARDANT DEPTH = 61.2 INCHES

WT = VOLUME x DENSITY

$WT_1 = WT_3 = WT_7 = WT_9 = 16.0 \times 29.5 \times 61.2 \times .0433 = 1250$ LBS

$WT_2 = WT_8 = 16.0 \times 59.0 \times 61.2 \times .0433 = 2500$ LBS

$WT_4 = WT_6 = 32.0 \times 29.5 \times 61.2 \times .0433 = 2500$ LBS

$WT_5 = 32.0 \times 59.0 \times 61.2 \times .0433 = 5000$ LBS

$\Sigma WT = 4 \times 1250 + 2 \times 2500 + 2 \times 2500 + 5000 = \underline{20,000}$ LBS

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GEOMETRY AND WEIGHT DISTRIBUTION

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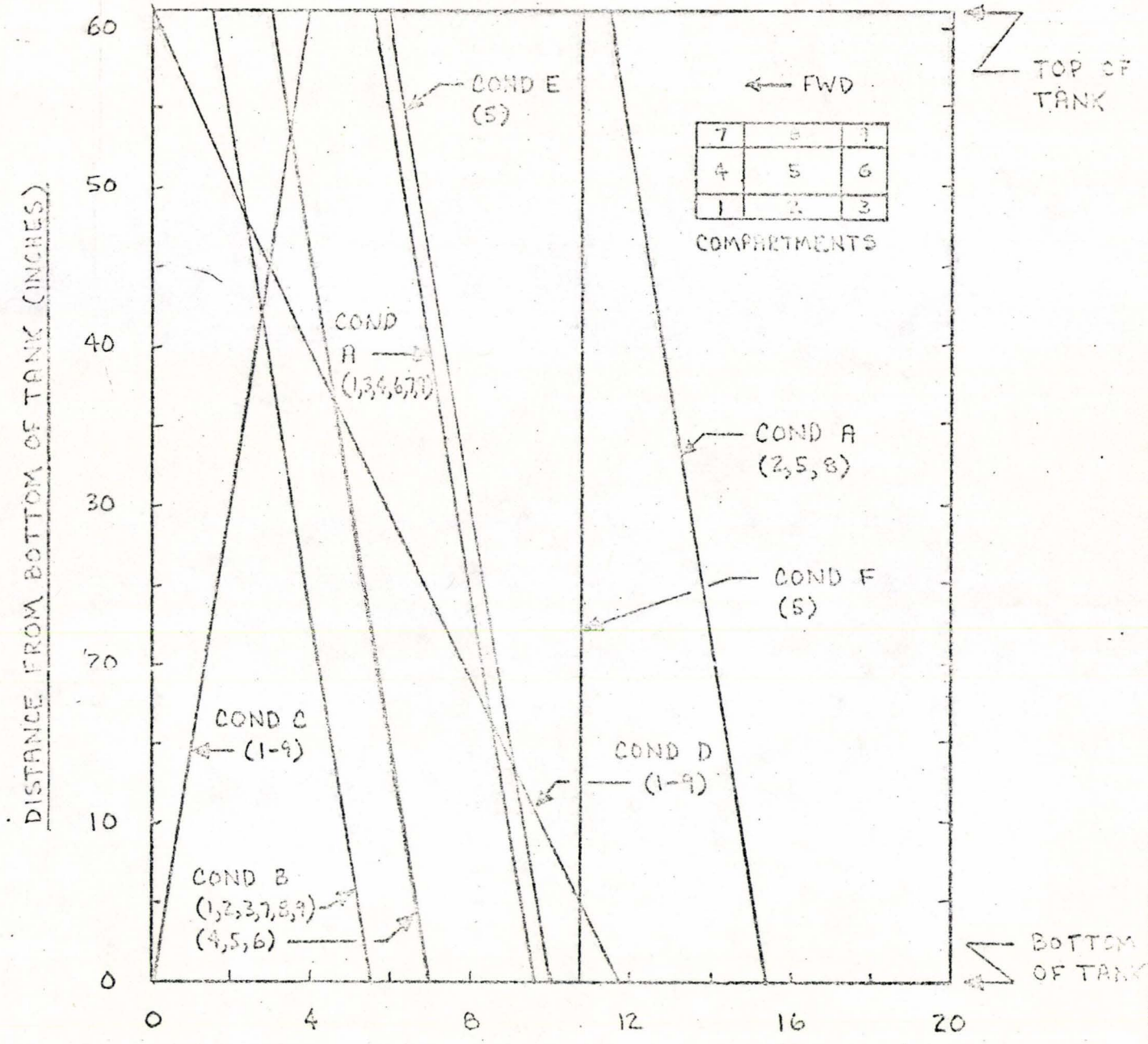

NOTES: • SEE PAGES 3 & 4 FOR LOADING CONDITIONS & WEIGHTS

• NUMBERS IN ( ) REFER TO COMPARTMENTS IN WHICH THE PRESSURES OCCUR

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ULTIMATE DESIGN PRESSURES.

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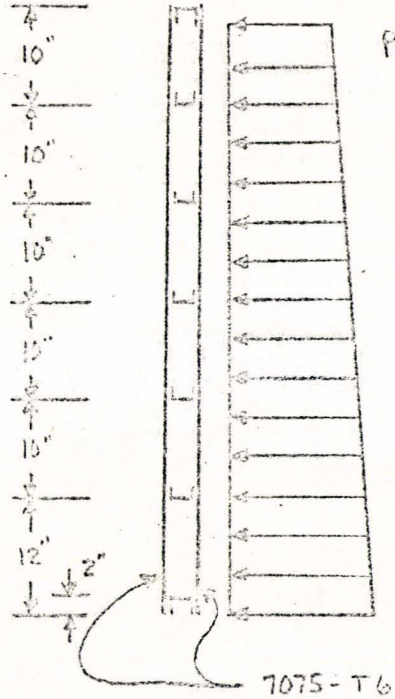
NOTE: THE MAX NORMAL PRESSURES OCCUR FOR LOADING CONDITION A, AND THEY ACT ON THE FORWARD WALL OF COMPARTMENTS 2, 5 & 8. (SEE P. 5)



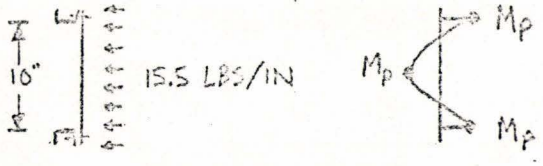
MATERIAL:

7075-T6 ALUM

F_{tu} = 75,000 PSI

LOWER SPAN IS CRITICAL BECAUSE OF HIGHER PRESSURE (P_b = 15.5 PSI)

ULT BENDING MOMENT, M_p, FOR UNIT STRIP OF SKIN



$M_p = \frac{1}{16} w l^2 = \frac{1}{16}(15.5)(10)^2$

M_p = 96.9 IN-LBS ULT ✓

ULT BENDING STRESS

$f_b = \frac{4M_p}{t^2} = \frac{4 \times 96.9}{(.08)^2}$

f_b = 60,563 PSI ULT ✓

M.S. $= \frac{75,000}{60,563} - 1$

⟶ M.S. = +.24

NOTE: CHANNEL ANALYSIS IS SHOWN ON PP. 9-11.

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SIDEWALL SKIN ANALYSIS FOR MAX NORMAL PRESSURE (COND A)

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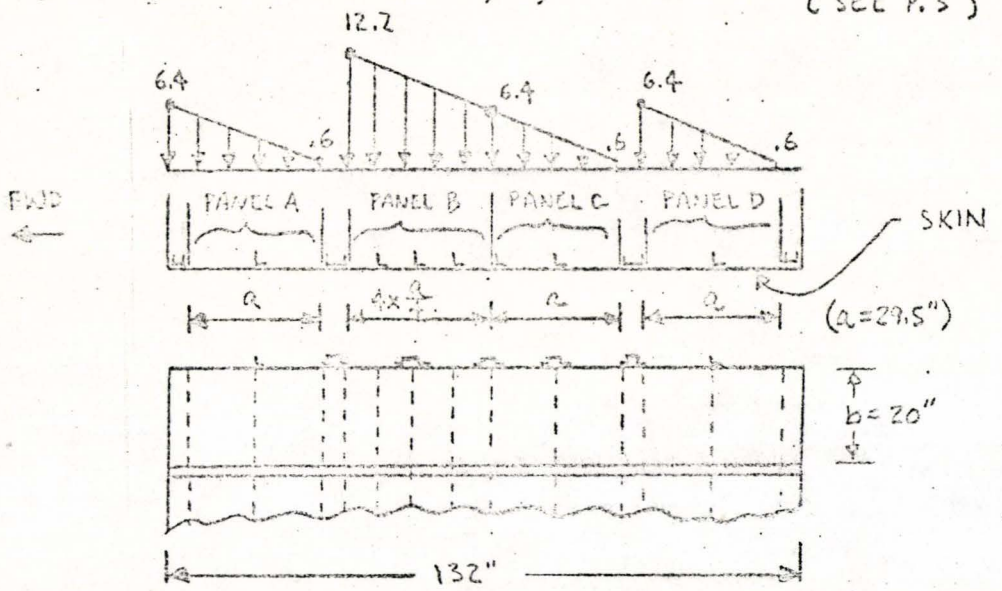
AVE ULT PRESSURE, P_o, ON 20" SPAN {COND A / SEE P. 5}



SKIN MATERIAL:
7075 - T6 ALUM
F_u = 75,000 PSI

SKIN THICKNESS
t = .080"

ULTIMATE PRESSURE CAPACITY, P_{ULT}, FOR PANELS A, C, & D

$P_{ULT} = \frac{\beta F_u t^2}{ab}$ {ROARK - P. 243 / UNIFORM PRESSURE WITH FIXED EDGES}

$\frac{b}{a} = \frac{20}{29.5} = .68 \Rightarrow \beta = 8.4$

$P_{ULT} = \frac{8.4 \times 75{,}000 \times .08^2}{29.5 \times 20}$

P_{ULT} = 6.9 PSI

$M.S. = \frac{\bar{P}_o}{P_{ULT}} - 1$

$M.S. = \frac{6.9}{3.5} - 1$

→ M.S. = +.94

NOTE: THE M.S. IS COMPUTED FOR THE AVERAGE STRESS, $\bar{P}_o$ = 3.5 PSI, ON PANELS A, C, & D. ALSO, THE EFFECT OF THE VERTICAL ANGLE WILL INCREASE THE STRENGTH.

ULTIMATE BENDING STRESS FOR PANEL B

ASSUME SKIN "BEAMS" PRESSURE TO VERTICAL ANGLES (SPAN = $\ell = \frac{a}{4} = 7.38$")

$M = \frac{1}{16} w \ell^2 = \frac{1}{16}(12.2)(7.38)^2$

M = 41.5 IN-LBS ULT

$f_b = \frac{4M}{t^2} = \frac{4 \times 41.5}{(.08)^2}$

f_b = 25,938 PSI ULT ✓

NOTE: ANALYSIS OF VERTICAL ANGLES SHOWN ON P. 12.

$M.S. = \frac{75{,}000}{25{,}938} - 1$

→ M.S. = +1.89

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UPPER EXTERNAL SKIN ANALYSIS FOR MAX NORMAL PRESSURE (COND A)

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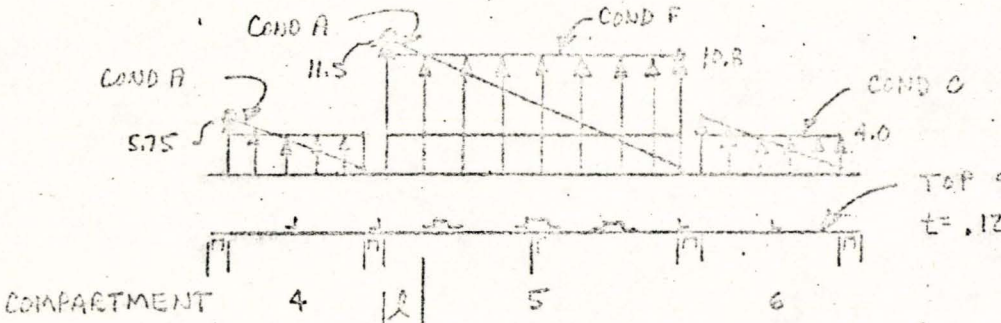
ULT PRESSURES, P_o, ON TOP SKIN



MATERIAL:
7075-T6 ALUM
F_{tu} = 75,000 PSI

MAX UNSUPPORTED LENGTH, ℓ = 13.75", IN COMPARTMENT 5

WIDTH OF COMPARTMENTS, b = 32"

ULTIMATE PRESSURE CAPACITY, P_{ULT}, FOR TOP SKIN ON COMPARTMENTS 4 & 6

$$P_{ULT} = \beta \frac{F_{tu} t^2}{a b}$$ { ROARK - P.243 UNIFORM PRESSURE WITH FIXED EDGES }

$$\frac{a}{b} = \frac{29.5}{32} = .92 \Rightarrow \beta = 6.0$$

$$P_{ULT} = \frac{6.0 \times 75{,}000 \times .125^2}{29.5 \times 32}$$

P_{ULT} = 7.45 PSI ✓

M.S. = $\frac{7.45}{4.0} - 1$

⟶ M.S. = +.86 ✓

NOTE: M.S. IS BASED ON COND C - P_o = 4.0 PSI

ULTIMATE BENDING STRESS FOR TOP SKIN ON COMPARTMENT 5

ASSUME SKIN "BEAMS" PRESSURE TO HORIZONTAL ⌐¬ SECTIONS (SPAN = ℓ = 13.75")

$$M = \frac{1}{16} w \ell^2 = \frac{1}{16}(11.5)(13.75)^2$$

M = 135.9 IN-LBS ULT ✓

$$f_b = \frac{4M}{t^2} = \frac{4 \times 135.9}{.125^2}$$

f_b = 34,790 PSI ULT ✓

M.S. = $\frac{75{,}000}{34{,}790} - 1$

⟶ M.S. = +1.16

NOTES: ANALYSIS OF HORIZONTAL ⌐¬ SECTIONS SHOWN ON P. 12.

CUTOUTS IN TOP SKIN MUST BE REINFORCED TO DEVELOP FULL STRENGTH OF SKIN.

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TOP SKIN ANALYSIS FOR MAX NORMAL PRESSURE (COND A, C, & F).

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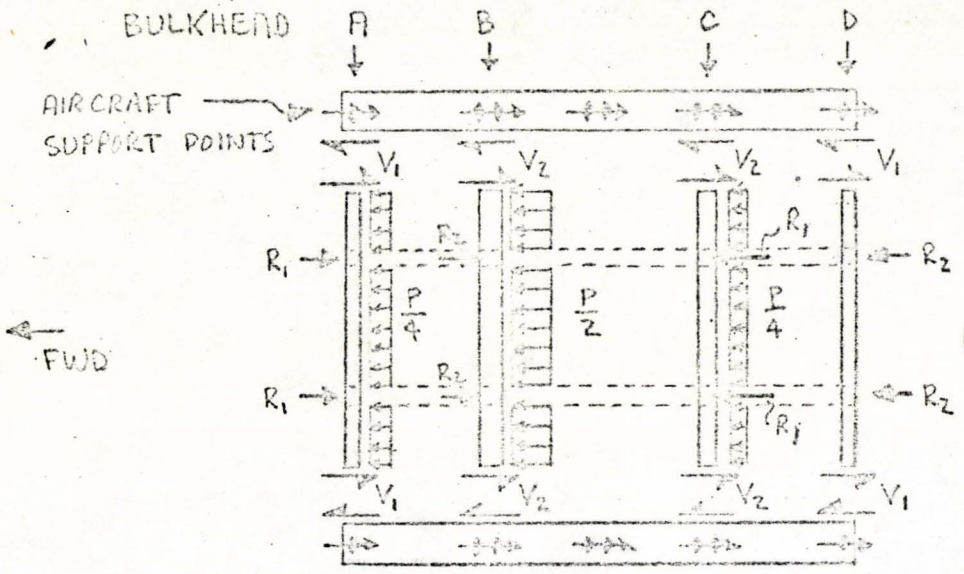


P = TOTAL ULT LOAD IN FORWARD DIRECTION

$P = 1.5 \times 3.0\,g's \times 22{,}500$ LBS

$P = 101{,}250$ LBS ULT

$V_1 = \frac{P}{12}$

$V_1 = 8438$ LBS ULT

$V_2 = 2V_1 = \frac{P}{6}$

$V_2 = 16{,}875$ LBS ULT

$R_1 = \frac{P}{24}$

$R_1 = 4219$ LBS ULT

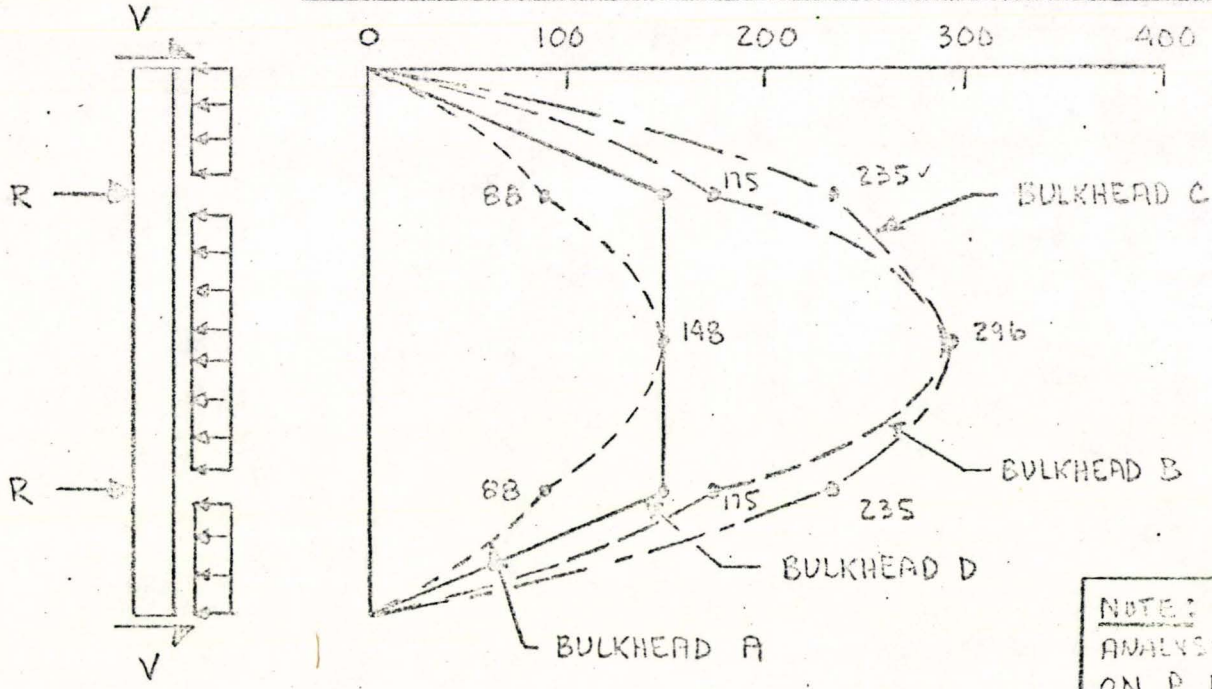
$R_2 = \frac{P}{12}$

$R_2 = 8438$ LBS ULT

NOTE:

THE ABOVE LOADS DO NOT INCLUDE THE EFFECTS OF THE VERTICAL LOADS DUE TO $n_z = 1.0$ g DOWN. THIS EFFECT IS SMALL, HOWEVER, AND WILL NOT SIGNIFICANTLY AFFECT THE RESULTS.

ULTIMATE BENDING MOMENTS FOR BULKHEADS (IN-KIPS)



NOTE: STRESS ANALYSIS SHOWN ON P. 11.

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INTERNAL CHANNEL LOADS FOR COND A

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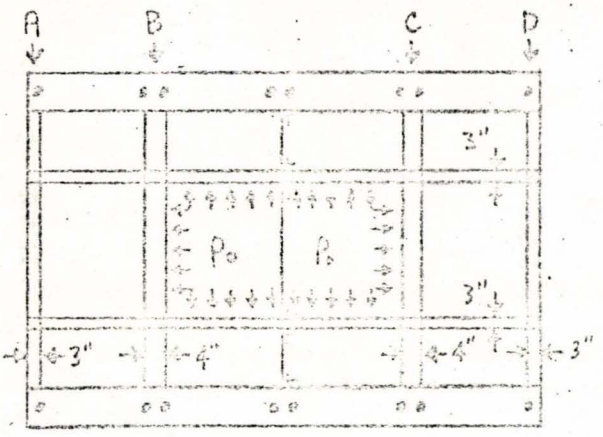
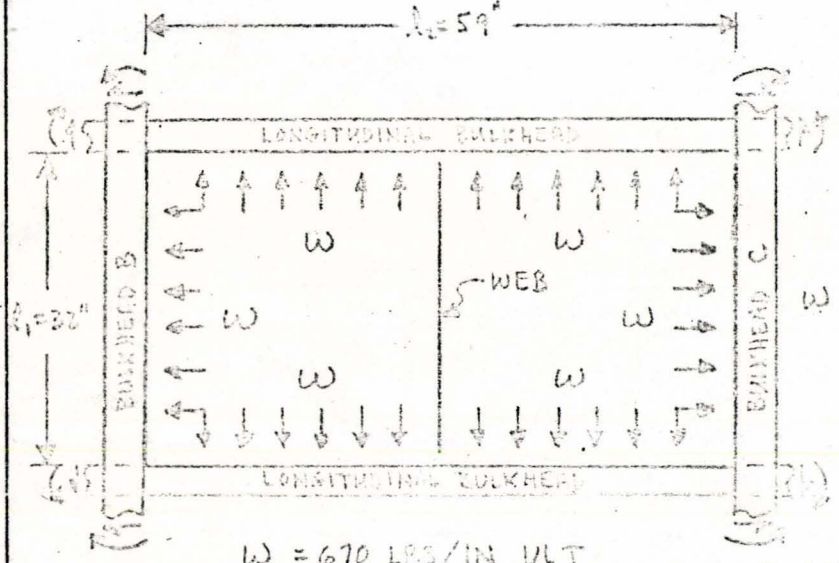
BULKHEAD

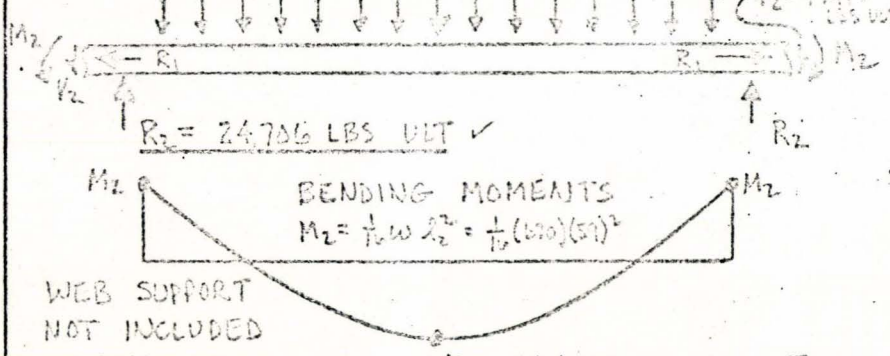


P_o = 10.3 PSI ULT

COND F (SEE P. 5)



w = 670 LBS/IN ULT



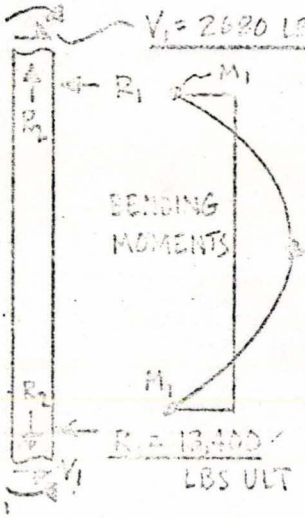
R_2 = 24,706 LBS ULT ✓

WEB SUPPORT NOT INCLUDED IN ANALYSIS

M_2 = 145,767 IN-LBS ULT ✓

M_1 = 42,850 IN-LBS ULT ✓

V_1 = 2680 LBS ULT ✓



$M_1 = \frac{1}{12} w l_1^2$

$= \frac{1}{12}(670)(30)^2$

M_1 = 42,850 IN-LBS ULT

BENDING MOMENTS

R_1 = 13,400 LBS ULT ✓

NOTE: COND A MOMENTS ARE HIGHER -- SEE P. 9

w = DISTRIBUTED HORIZONTAL LOAD FOR ENTIRE DEPTH OF TANK

w = PRESSURE X DEPTH

= 10.3 PSI x 62 IN

w = 670 LBS/IN ULT

NOTE: THE LONGITUDINAL BULKHEAD HAS A 3" DEPTH AND A CROSS-SECTION SIMILAR TO THE FORWARD AND AFT BULKHEADS (A & D) SHOWN ON P. 9. THE MAX BENDING MOMENT IN THE LONGITUDINAL BULKHEAD (M=145,767) IS SLIGHTLY LESS THAN IN THE THE FARWARD AND AFT BULKHEADS (M=148,000). SEE P. 9.

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INTERNAL CHANNEL LOADS FOR COND F

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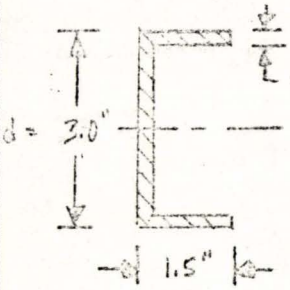
ANALYSIS OF 3" CHANNELS FOR FWD & AFT BULKHEADS, AND LONGITUDINAL BULKHEADS (SEE PP 9 & 10)



$$I = I_{WEB} + 2A_{FLANGE}\left(\frac{d-t}{2}\right)^2$$

$$= \frac{.125}{12}(3.0)^3 + 2(.125\times1.375)\left(\frac{3.0-.125}{2}\right)^2$$

$$I = .99 \text{ IN}^4$$

MATERIAL:

6061-T6 ALUM
F_{tu} = 43,000 PSI

RIVETS - NAS/5 (D = $\frac{5}{32}$")
SHEAR STRENGTH = 595 LBS

THE BULKHEADS ARE DIVIDED INTO 6 EQUAL SPANS (SEE P. 6), EACH CHANNEL MUST THEREFORE SUPPORT 1/6 OF THE TOTAL MOMENTS SHOWN ON PP. 9 & 10. THE MAX ULT MOMENT FOR THE 3" CHANNELS IS THEREFORE $\frac{1}{6}\times148{,}000 = 24{,}667$ IN-LBS ULT. (COND A: P. 9)

BENDING STRESS - INCLUDE EFFECT OF SKIN

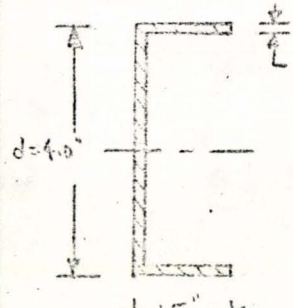
$$f_b = \frac{Mc}{I} = \frac{24{,}667\times1.5}{.99}$$

f_b = 37,374 PSI ULT ✓ ⟶ $M.S._1 = \frac{43{,}000}{37{,}374} - 1$

$M.S._1 = +.15$

ANALYSIS OF 4" CHANNELS FOR INTERMEDIATE BULKHEADS, B & C. (COND A - P. 9)

THE CRITICAL BENDING STRESS OCCURS WHERE BULKHEAD C CROSSES THE LONGITUDINAL BULKHEAD, EVEN THOUGH THE NET MOMENT AT THE INTERSECTION (M_A = 235,000) IS LESS THAN THE MOMENT AT MIDSPAN (M_1 = 296,000), THE BENDING STRESS IS CRITICAL AT THE INTERSECTION BECAUSE THE SKIN IS NOT EFFECTIVE IN BENDING AT THIS POINT. MOMENT PER CHANNEL = $\frac{1}{6}\times235{,}000$ = 39,167 IN-LBS ULT



$$I = I_{WEB} + 2A_{FLANGE}\left(\frac{d-t}{2}\right)^2$$

$$= \frac{.125}{12}(4.0)^3 + 2(.125\times1.375)\left(\frac{4.0-.125}{2}\right)^2$$

$$I = 1.96 \text{ IN}^4$$

BENDING STRESS

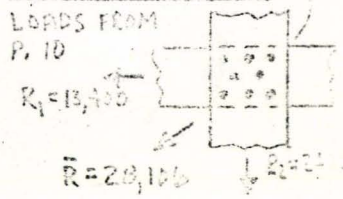
$$f_b = \frac{Mc}{I} = \frac{39{,}167\times2.0}{1.96}$$

f_b = 39,966 PSI ULT ✓ ⟶ $M.S. = \frac{43{,}000}{39{,}966} - 1$

$M.S. = +.08$

RIVET ANALYSIS (SEE P. 12)

LOADS FROM P. 10



LOADS ARE FOR TOTAL [illegible] OF TANK - USE $\frac{1}{6}\bar{R}$ = [illegible] FOR EACH INTERSECTION

$M.S._1 = \frac{3{,}350}{4{,}034} - 1$

$M.S._1 = +.02$

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STRESS ANALYSIS FOR INTERNAL CHANNELS

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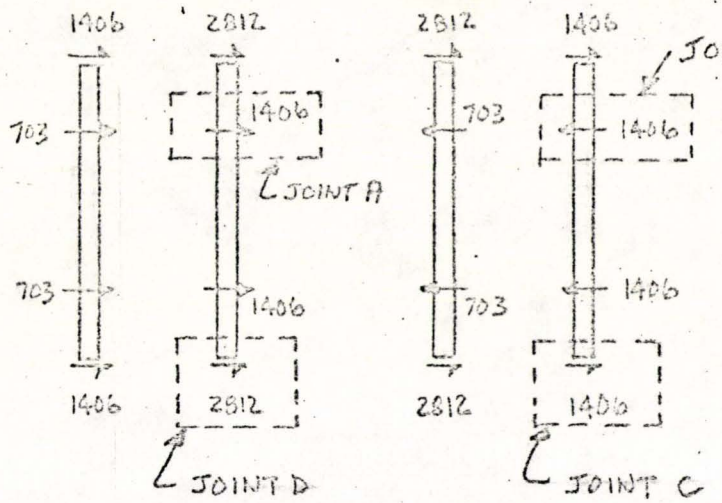
RIVET ANALYSIS FOR COND A LOADS



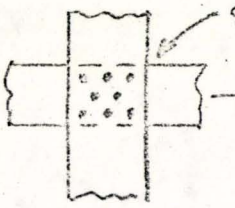
RIVET ANALYSIS FOR COND F LOADS IS SHOWN ON P. 11

← LOADS SHOWN ARE FOR A SINGLE CHANNEL. THEY ARE 1/6 OF THE TOTAL LOADS SHOWN ON P. 9.

AD/5 RIVETS ($D=\frac{5}{32}$")
SHEAR STRENGTH = 596 LBS

$$M.S._1 = \frac{\text{ALLOWABLE LOAD}}{\text{ACTUAL LOAD}} - 1$$

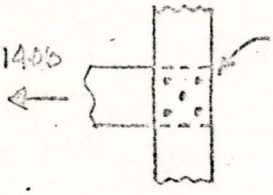
JOINT A



$$M.S._1 = \frac{8 \times 596}{1406} - 1 \longrightarrow M.S._1 = +.36$$

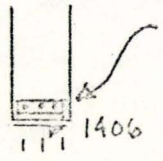
NOTE: COND F LOADS ARE MORE CRITICAL FOR THIS JOINT. SEE P. 11

JOINT B



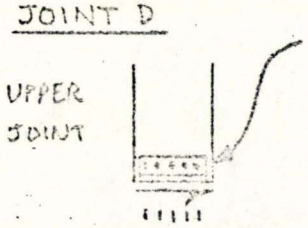
$$M.S._1 = \frac{5 \times 596}{1406} - 1 \longrightarrow M.S._1 = +.06$$

JOINT C



$$M.S._1 = \frac{3 \times 596}{1406} - 1 \longrightarrow M.S._1 = +.27$$

JOINT D



LOWER JOINTS HAVE MORE THAN 5 RIVETS

$$M.S._1 = \frac{5 \times 596}{2812} - 1 \longrightarrow M.S._1 = +.06$$

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STRESS ANALYSIS FOR INTERNAL CHANNELS

AEROSPACE & DEFENSE GROUP
GOVERNMENT & AERONAUTICAL PRODUCTS DIVISION

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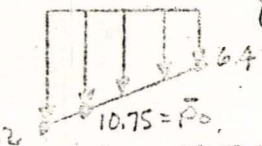
ANALYSIS OF VERTICAL ANGLES ON SIDE SKIN (SEE P.7)

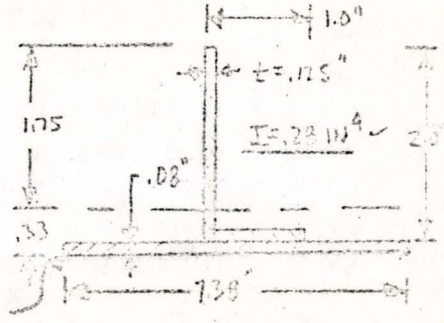
PANEL B (SEE P.7) — CRITICAL VERTICAL ANGLE {CLEAR VERTICAL} {SPAN = ℓ = 20"}



CRITICAL VERTICAL ANGLE SUPPORTS
EFFECT SPAN $\frac{\ell}{7} = \frac{235}{7} = 7.38"$

MATERIAL (L ∠)

6061-T6 ALUM
F_{tu} = 43,000 PSI
RIVETS - AD/6 (D = 3/16")
TENSILE STRENGTH = 800 LBS



BENDING MOMENT SUPPORTED BY VERTICAL ANGLE

$M = \frac{1}{8} w \ell^2 = \frac{1}{8}(\bar{P}_o \times \frac{8}{7})(\ell)^2 = \frac{1}{8}(10.75 \times \frac{8}{7})(20)^2$

M = 3967 IN-LBS ULT ✓

BENDING STRESS

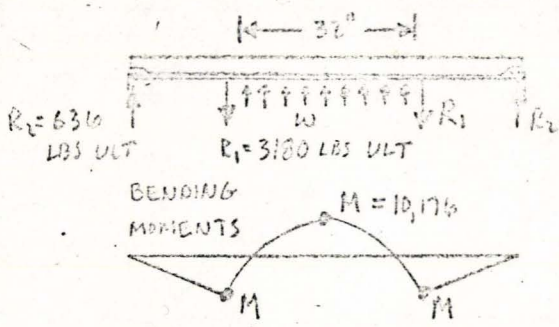
$f_b = \frac{Mc}{I} = \frac{3967 \times 1.75}{.28}$

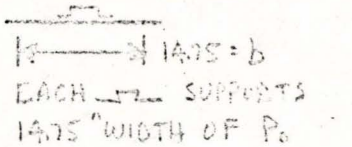
f_b = 24,794 PSI ULT ✓

$M.S._1 = \frac{43,000}{24,794} - 1$

$M.S._1 = +.73$

ANALYSIS OF HORIZONTAL ⌐ SECTIONS ON TOP SKIN





EACH ⌐ SUPPORTS 14.75" WIDTH OF P_o

$\omega = p_o b = 10.8 \times 14.75$

ω = 159 LBS/IN ULT

I = .22 IN⁴ ✓

BENDING MOMENT

$M = \frac{1}{10} \omega \ell^2 = \frac{1}{10}(159)(32)^2$

M = 10176 IN-LBS ULT ✓

BENDING STRESS

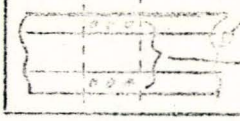
$f_b = \frac{Mc}{I} = \frac{10176 \times .09}{.22}$

f_b = 37,004 PSI ULT ✓

$M.S._1 = \frac{43,000}{37,004} - 1$

$M.S._1 = +.16$ ✓

RIVET ANALYSIS FOR R_1 = 3180 LBS TENSION



$M.S._1 = \frac{6 \times 800}{3180} - 1$

$M.S._1 = +.51$

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STRESS ANALYSIS FOR VERTICAL ANGLES ON SIDE SKIN AND HORIZONTAL ⌐ SECTIONS ON TOP SKIN

AEROSPACE & DEFENSE GROUP
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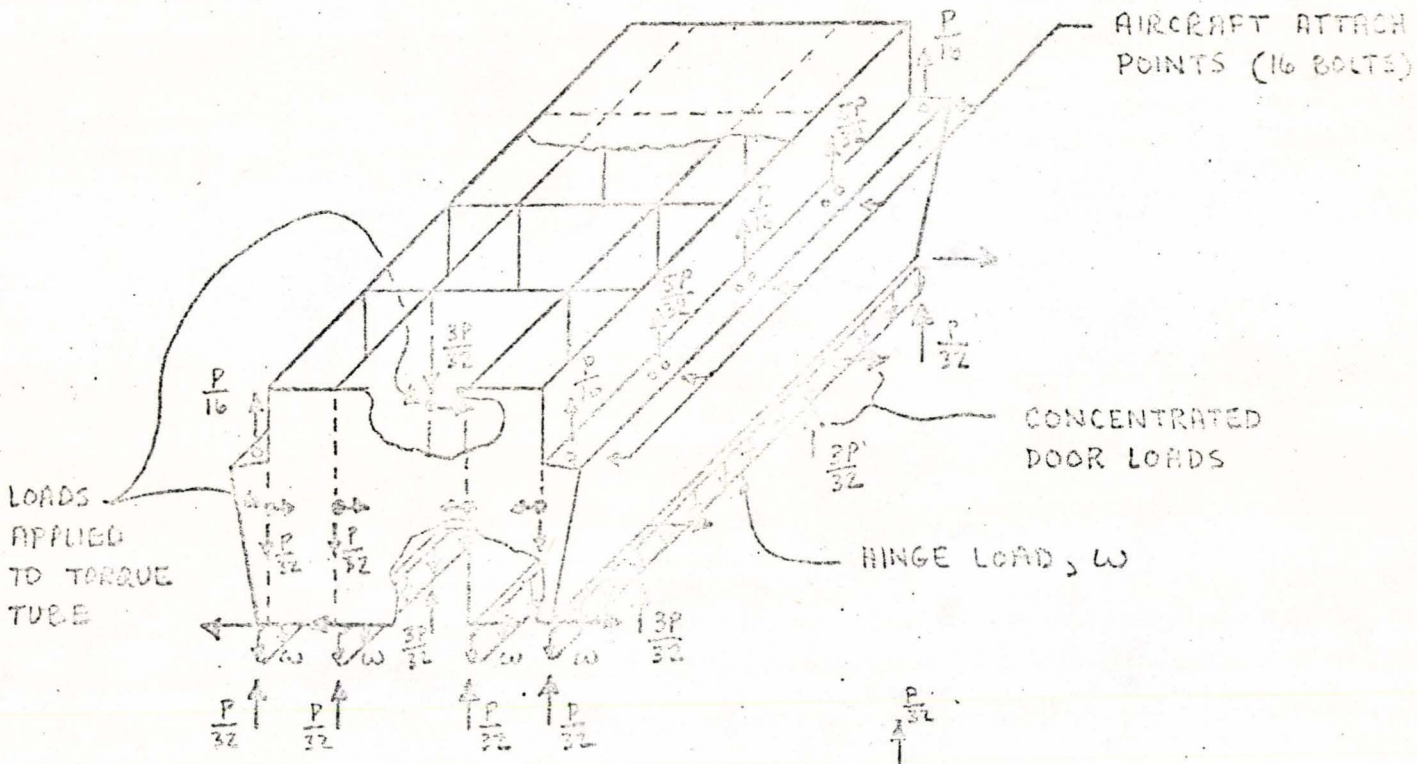
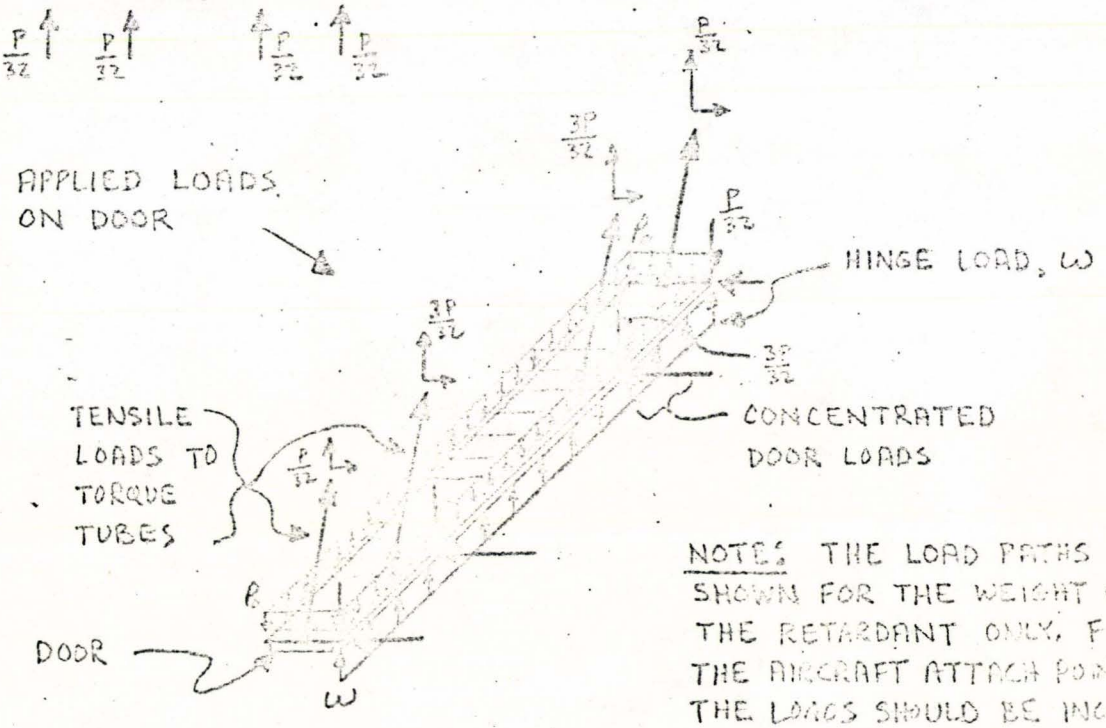
P = ULT DOWNWARD INERTIAL RETARDANT FORCE

P = 1.5 x 9.45 g's x 20,000 LBS

P = 40,000 LBS ULT

APPLIED LOADS ON TANK WITH DOORS REMOVED





NOTE: THE LOAD PATHS ARE SHOWN FOR THE WEIGHT OF THE RETARDANT ONLY. FOR THE AIRCRAFT ATTACH POINTS, THE LOADS SHOULD BE INCREASED TO ACCOUNT FOR STRUCTURE WEIGHT.

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LOAD PATHS FOR COND D

AEROSPACE & DEFENSE GROUP
GOVERNMENT & AERONAUTICAL PRODUCTS DIVISION

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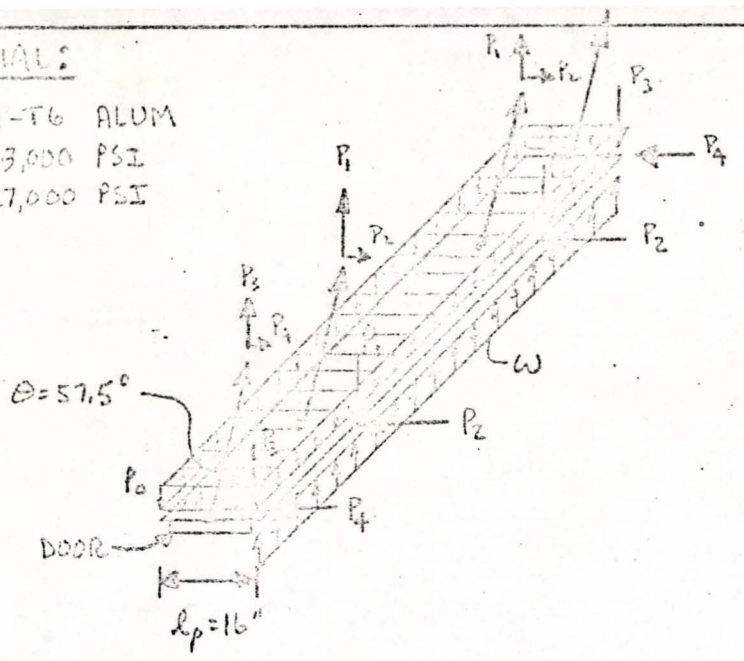
MATERIAL:

6061-T6 ALUM

$F_{tu} = 42,000$ PSI

$F_{su} = 27,000$ PSI



ULT LOADS FOR COND D

$P_0 = 11.9$ PSI ✓ (P.5)

$\omega = P_0 \ell_p = 11.9 \times 16$

$\omega = 190$ LBS/IN ✓

$P_1 = \frac{3}{32} P = \frac{3}{32}(90,000)$ {SEE P.14}

$P_1 = 3438$ LBS ULT ✓

$P_2 = P_1 / \tan\theta = 8438/1.57$

$P_2 = 5375$ LBS ULT ✓

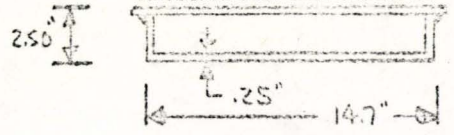
$P_3 = \frac{P}{32} = 90,000/32$ {SEE P.14}

$P_3 = 2813$ LBS ULT ✓

$P_4 = P_3 / \tan\theta = 2813/1.57$

$P_4 = 1792$ LBS ULT ✓

$P_{max} = 15.5$ PSI ULT (COND A - P.5)



NOTE: THE MAX PRESSURE ON THE DOOR OCCURS DURING COND "A" (P_{max} = 15.5 PSI), HOWEVER, THIS IS A LOCALIZED PRESSURE WHICH OCCURS ONLY AT THE FWD END OF COMPARTMENTS 2,5,8 FOR OVERALL DOOR DESIGN, COND D GOVERNS BECAUSE THE PRESSURES (P_0 = 11.9 PSI) ACTS UNIFORMLY ON ALL DOORS.

CHECK LOCALIZED BENDING IN TOP PLATE

$M = \frac{1}{8} P_{max} \ell^2$

$= \frac{1}{8}(15.5)(14.7 - 2\times.25)^2$

$M = 391$ IN-LBS/IN ULT ✓

$f_b = \frac{6M}{t^2} = \frac{6\times391}{(.25)^2}$

$f_b = 37,536$ PSI ULT ✓ ⟶

$M.S._1 = \frac{43,000}{37,536} - 1$

M.S. = +.15 ✓

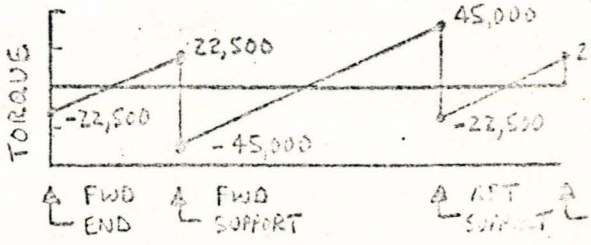
CHECK SHEAR STRESS DUE TO TORQUE

$T_{max} = \frac{2}{3} P_1 \frac{\ell_p}{2} = \frac{2}{3}(8438)\frac{16}{2}$

$T_{max} = 45,000$ IN-LBS ULT ✓

$q = \frac{T_{max}}{2A} = \frac{45,000}{2(2.25\times14.45)}$ {SHEAR FLOW}

$q = 692$ LBS/IN ULT ✓



$f_s = \frac{q}{t} = \frac{692}{.25}$ ⟶ $f_s = 2768$ PSI ULT ✓ ⟶ $M.S. = \frac{27,000}{2768} - 1$ ⟶ M.S. = LARGE ✓

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DOOR ANALYSIS

AEROSPACE & DEFENSE GROUP
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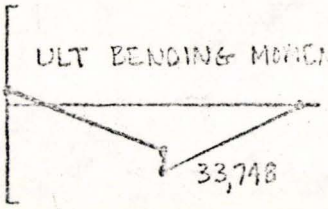
DOOR SUPPORT

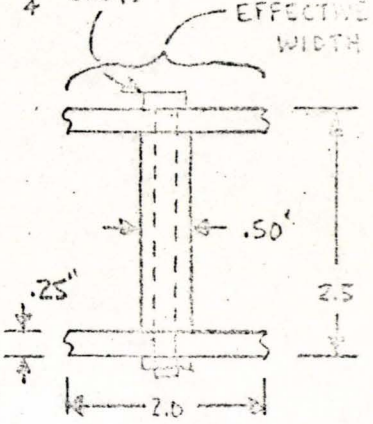
INTERMEDIATE SUPPORT SEE P. 15

$q = 1038$ {INCLUDES BOTH SIDES OF SUPPORT 1.5×692}

ULT BENDING MOMENTS



WEB ATTACHED TO SKIN WITH 6 - $\frac{1}{4}$" BOLTS



$I = I_{WEB} + 2A_{FLANGE}\left(\frac{2.5}{2}\right)^2$

$= \frac{.5}{12}(2)^3 + 2(.25\times2.0)(1.25)^2$

$I = 1.60\ IN^4$ ✓

BENDING STRESS

$f_b = \frac{Mc}{I} = \frac{33,748 \times 1.25}{1.6}$

$f_b = 26,366$ PSI ULT ✓

$M.S. = \frac{43,000}{26,366} - 1$

$M.S. = +.63$ ✓

SHEAR STRESS IN BOLTS {MS9490-38, F_s = 75,000 PSI}

$12P_s = qs$ → P_s = SHEAR IN BOLT; s = DISTANCE AT WHICH SHEAR FLOW ACTS

$P_s = \frac{1038}{12}(2\times14.45 + 2\times2.25)$

$P_s = 2889$ LBS ULT ✓

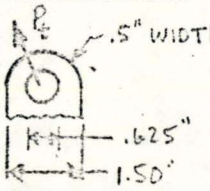
$f_s = P_s/A_s = 2889/(.1257)$ (SHEAR STRESS)

$f_s = 58,654$ PSI ULT ✓

$M.S. = \frac{75,000}{58,654} - 1$

$M.S. = +.27$ ✓

LUG ANALYSIS



$P_t = \sqrt{P_1^2 + P_2^2} = \sqrt{8438^2 + 5275^2}$

$P_t = 10,005$ LBS ULT

TENSILE STRESS AT HOLE IN LUG

$f_t = \frac{P_t}{A} = \frac{10,005}{.5(1.5-.625)}$

$f_t = 22,869$ PSI ULT ✓

$M.S. = \frac{43,000}{22,869} - 1$

$M.S. = +.88$ ✓

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DOOR ANALYSIS (CONT)

AEROSPACE & DEFENSE GROUP
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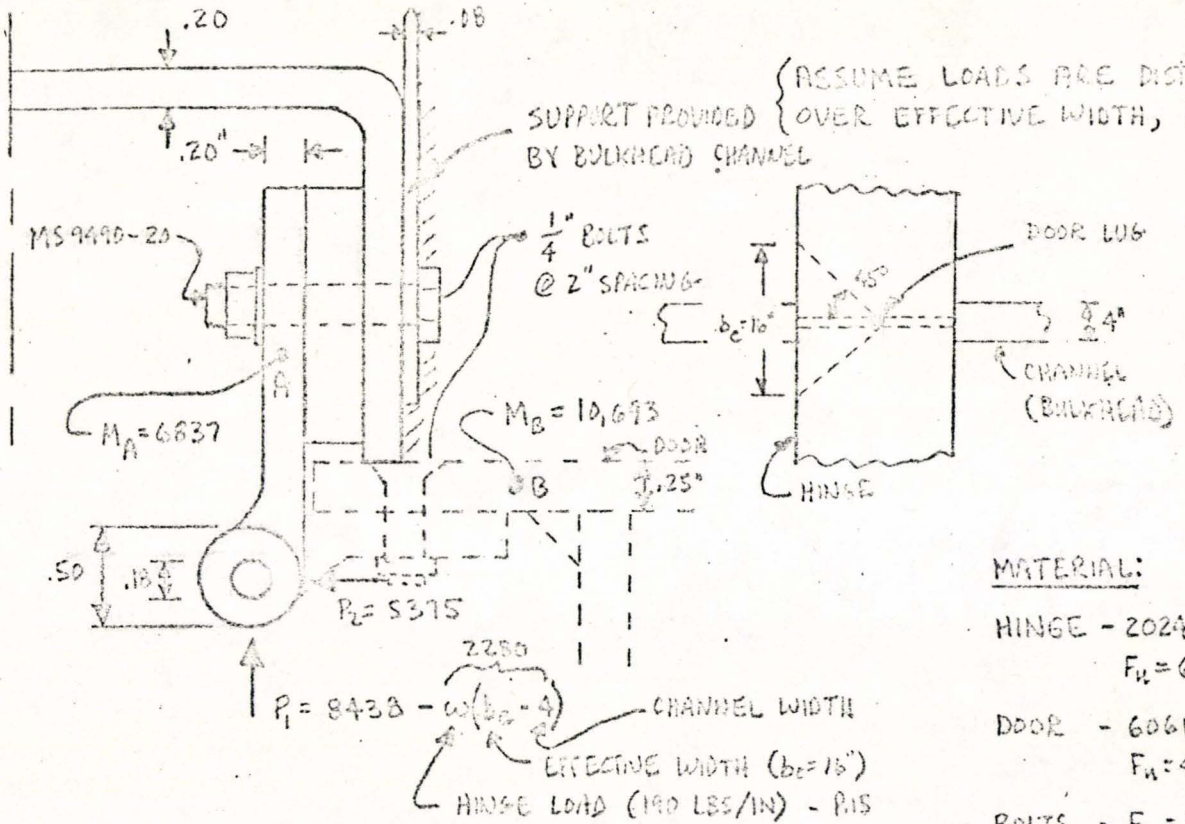

MATERIAL:

HINGE - 2024-T4 ALUM
F_u = 60,000 PSI

DOOR - 6061-T6 ALUM
F_u = 42,000 PSI

BOLTS - F_s = 75,000 PSI

BENDING STRESS AT "A" IN HINGE

$M_A = (8438 - 2280) \times .15" + 5375 \times 1.1" = 6837$ IN-LBS ULT ✓

$f_b = \frac{4M}{bt^2} = \frac{4 \times 6837}{16 \times .25^2}$

f_b = 42,731 PSI ULT ✓

$M.S. = \frac{60,000}{42,731} - 1$ ⟶ M.S. = +.40 ✓

BENDING STRESS AT "B" IN DOOR

$M_B = (8438 - 2280) \times 1.3" + 5375 \times .5" = 10,693$ IN-LBS ULT ✓

$f_b = \frac{4M}{bt^2} = \frac{4 \times 10,693}{16 \times .25^2}$

f_b = 42,772 PSI ULT ✓

$M.S. = \frac{43,000}{42,772} - 1$ ⟶ M.S. = +.01 ✓

SHEAR STRESS IN BOLTS

8 BOLTS EFFECTIVE IN VERTICAL SHEAR

$f_s = P/A_s = (8438 - 2280)/(8\pi \cdot .125^2)$

f_s = 15,681 PSI ULT ✓

$M.S. = \frac{75,000}{15,681} - 1$ ⟶ M.S. = +3.8 ✓

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DOOR HINGE ANALYSIS

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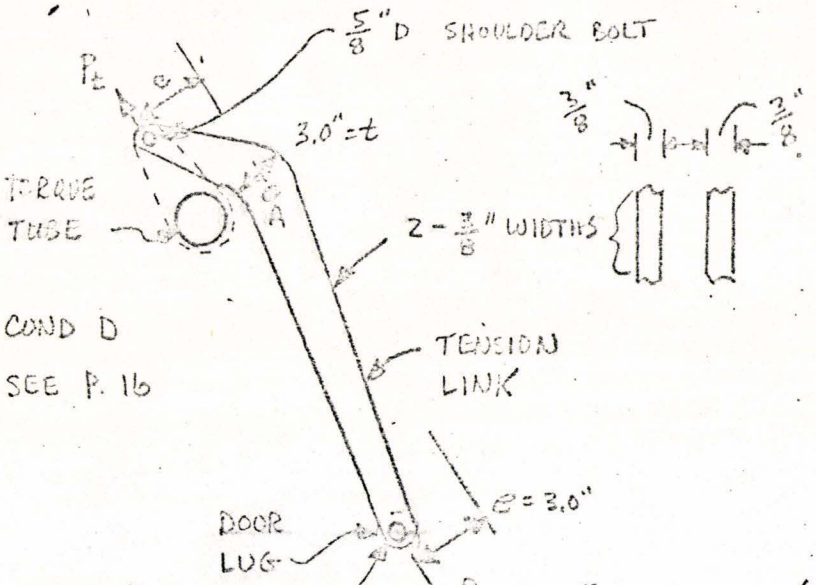

MATERIALS:

LINK 6061-T6 ALUM
F_{tu} = 43,000 PSI

BOLT F_s = 75,000 PSI

FIND STRESS IN LINK AT "A"

$$f_t = \frac{6M}{bt^2} + \frac{P_t}{bt} = \frac{6 \times (10{,}005 \times 3")}{(2 \times \frac{3}{8}) \times (3.0)^2} + \frac{10{,}005}{(2 \times \frac{3}{8}) \times (3.0)}$$

$$= 26{,}680 + 4447$$

f_t = 31,127 PSI ULT ✓

$$M.S. = \frac{43{,}000}{31{,}127} - 1$$

$$M.S. = +.38$$

SHEAR STRESS IN SHOULDER BOLTS

$f_s = P_t / A_s$ = 10,005 / (2π · .3125²) (DOUBLE SHEAR)

f_s = 16,306 PSI ULT ✓

$$M.S. = \frac{75{,}000}{16{,}306} - 1$$

$$M.S. = +3.6$$

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TENSION LINK ANALYSIS

AEROSPACE & DEFENSE GROUP
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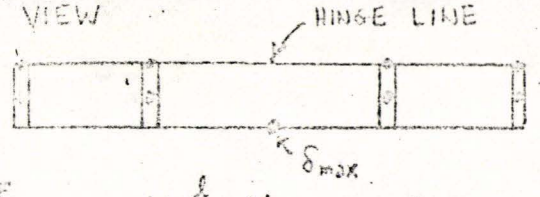
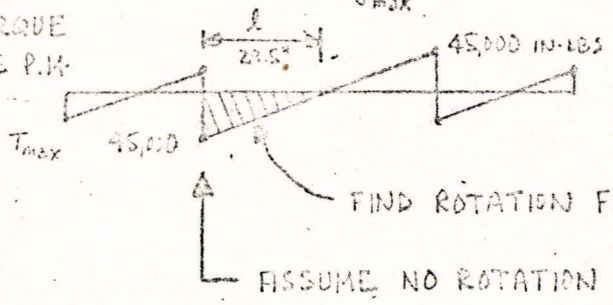
PLAN VIEW



COND D ⇒ p_o = 11.9 PSI – P.5

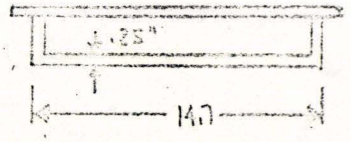
ULT TORQUE SEE P.14



FIND ROTATION FROM SUPPORT TO MID-SPAN, θ_{max}

ASSUME NO ROTATION AT SUPPORT

CROSS-SECTION OF DOOR



$$K = \frac{4A^2t}{s} = \frac{4(14.45 \times 2.25)^2 \times .25}{2(14.45+2.25)}$$ { ROARK P.195 }

$K = 31.6\ IN^4$ ✓

FIND ROTATION AT MID-SPAN, θ_{max}

$$\theta_{max} = \frac{\bar{T}l}{KG}$$

WHERE $\bar{T} = \frac{T_{max}}{2} = 22,500$ (θ_{max} FROM ROARK – P.195)

$l = 29.5"$

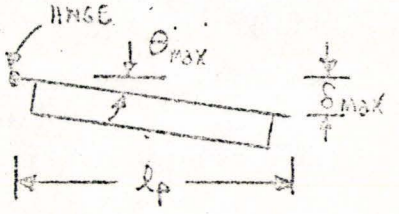
$K = 31.6"$

$G = 3.8 \times 10^6$

$$= \frac{22,500 \times 29.5}{31.6 \times 3.8 \times 10^6}$$

$\theta_{max} = .00552$ RADIANS ULT ✓

FIND DEFLECTION AT MID-SPAN, δ_{max}



$\delta_{max} = \theta_{max}\, l_p$

$= .00553 \times 16"$

$\delta_{max} = .088"$ (DUE TO ULT PRESSURE) ✓

$\delta_{max} = .059"$ (DUE TO LIMIT PRESSURE) ✓

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DOOR DEFLECTION ANALYSIS FOR COND D

AEROSPACE & DEFENSE GROUP
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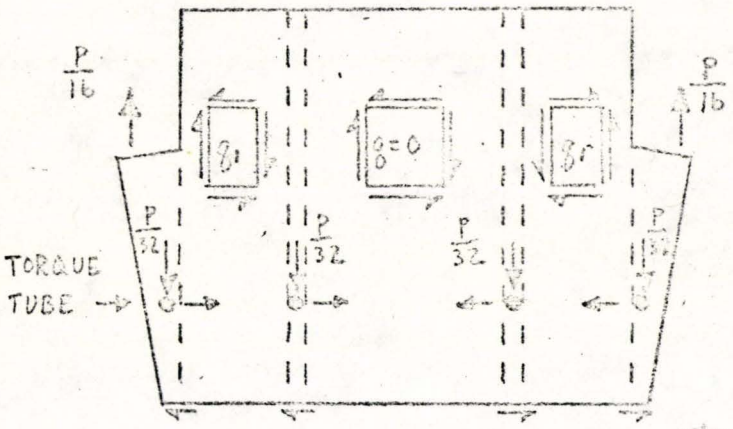
P = 90,000 LBS ULT

SEE P. 14

NOTE: THE LOADS SHOWN ARE FOR THE RETARDANT ONLY. FOR THE STRESS ANALYSIS OF THE ATTACH POINTS, THE LOADS WILL BE INCREASED TO ACCOUNT FOR THE STRUCTURE WEIGHT

FORWARD & AFT BULKHEADS

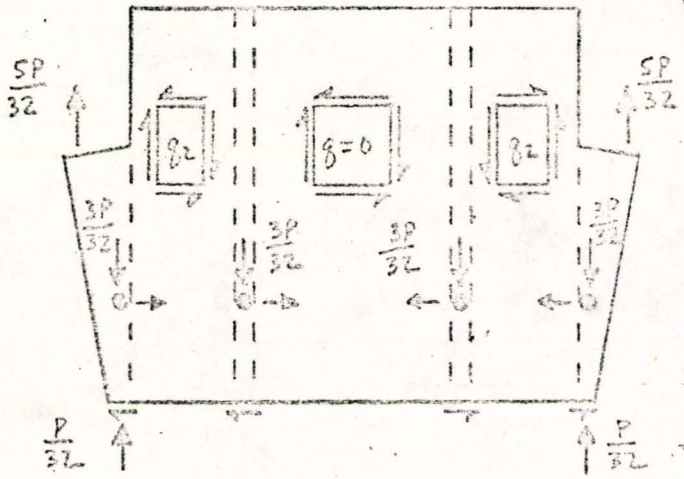


THE HINGE LOADS (SEE P.14) ARE "BEAMED" TO THE BULKHEADS AND THEY CANCEL OUT THE VERTICAL CONCENTRATED DOOR LOADS (SEE P.14)

$q_1 = (P/32)$ / TOTAL DEPTH $= \frac{90000}{32 \times 60}$

$q_1 = 47$ LBS/IN ULT

INTERMEDIATE BULKHEADS

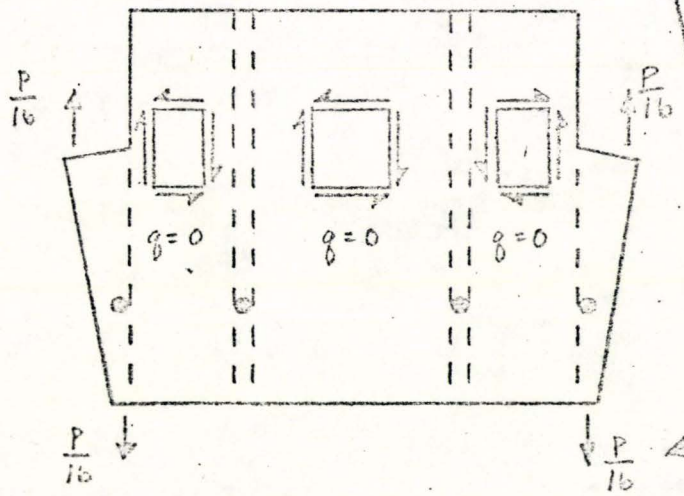


IT IS ASSUMED THE CENTER PARTITION DOES NOT DISTRIBUTE ANY OF THE INTERNAL HINGE LOADS TO THE SUPPORTS, SO THE CONCENTRATED DOOR LOADS ARE COMPLETELY CANCELED. A PORTION OF THE EXTERNAL HINGE LOADS IS TRANSFERRED DIRECTLY TO THE CENTER SUPPORTS (ATTACH POINTS), SO THE CONCENTRATED DOOR LOADS ARE NOT COMPLETELY CANCELED.

$q_2 = \frac{3P}{32}$ / TOTAL DEPTH $= \frac{3 \times 90000}{32 \times 60}$

$q_2 = 141$ LBS/IN ULT

CENTER PARTITION



A PORTION OF THE EXTERNAL HINGE LOADS IS TRANSFERRED DIRECTLY TO THE SUPPORT.

THE PARTITION CARRIES NO SHEAR.

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BULKHEAD LOADS FOR COND D

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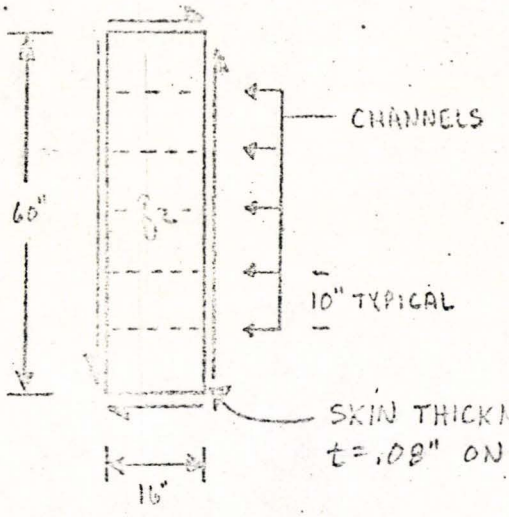
INTERMEDIATE BULKHEAD HAS MAX SHEAR FLOW, $q_2 = 141$ LBS/IN ULT (SEE P. 20)



MATERIAL:

SKIN - 7075-T6 ALUM
$F_s = 45{,}000$ PSI
$E = 10^7$ PSI
RIVETS AD/S ($D = \frac{5}{16}$")
SHEAR STRENGTH = 5)16 (C)

FIND BUCKLING STRESS OF SKIN, F_{CRIT}

(LARGEST UNSUPPORTED SPAN IS 10" x 16")

$F_{CRIT} = \frac{\pi^2 K_s E}{12(1-\nu^2)} \left(\frac{t}{b}\right)^2$ (BRUHN - P. C5.6) $\frac{a}{b} = \frac{16}{10} = 1.6 \Rightarrow K_s = 7$

$= \frac{\pi^2 (7)\, 10^7}{12(1-.3^2)} \left(\frac{.08}{10}\right)^2$

$F_{CRIT} = 4049$ PSI ✓

SHEAR STRESS IN SKIN

$f_s = q_2/t = \frac{141}{2 \times .08}$

$f_s = 881$ PSI ULT ✓

M.S. $= \frac{4049}{881} - 1$

⟶ M.S. $= +3.6$ ✓

FIND SHEAR FORCE PER RIVET, R_s

EACH SKIN HAS TWO ROWS OF RIVETS SPACED AT $s = 1.25$"

$R_s = q_2\left(\frac{s}{2}\right) = 141\left(\frac{1.25}{4}\right)$

$R_s = 44.1$ LBS PER RIVET ULT ✓

M.S. $= \frac{591}{44.1} - 1$

⟶ M.S. $= +12.5$ ✓

NOTE: RIVET SPACING IS GOVERNED BY LEAKAGE REQUIREMENTS AND THE STRUCTURAL M.S. IS THEREFORE VERY LARGE

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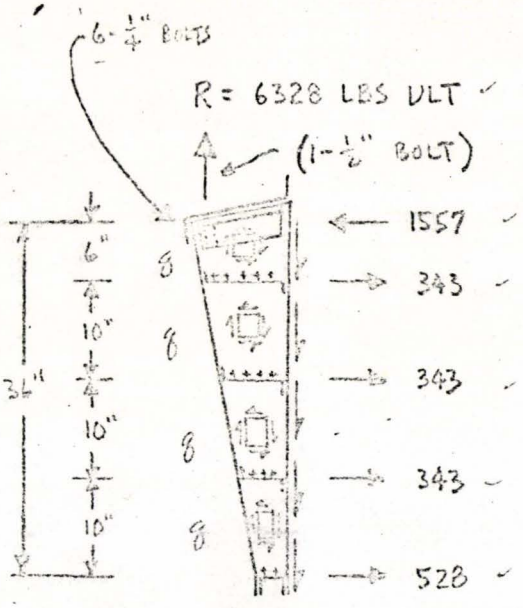
BULKHEAD SHEAR FLOW & RIVET ANALYSIS



FROM P.14, R IS GIVEN FOR THE WEIGHT OF THE RETARDANT ONLY. TO INCLUDE THE WEIGHT OF THE STRUCTURE, IT MUST BE INCREASED BY 12.5%

$$R = 1.125\,\frac{P}{16} = 1.125\,\frac{90{,}000}{16}$$

$$\underline{R = 6328 \text{ LBS ULT}} \quad ✓$$

EQUAL SHEAR FLOW, q, IN ALL PANELS

$$q = \frac{R}{x} = \frac{632.8}{36}$$

$$\underline{q = 176 \text{ LBS/IN ULT}} \quad ✓$$

OUTER SKIN ON FWD & AFT BULKHEADS IS CONTINUOUS. THEREFORE, THE HORIZONTAL LOADS ARE SIMPLY TRANSFERRED INTO THE OUTER SKIN.

OUTER SKIN ⇒ 6061-T6 ALUM, $t = .063"$, $F_{CRIT} = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t}{b}\right)^2$

$$= \frac{\pi^2 10(10^6)}{12(1-.3^2)}\left(\frac{.063}{16}\right)^2$$

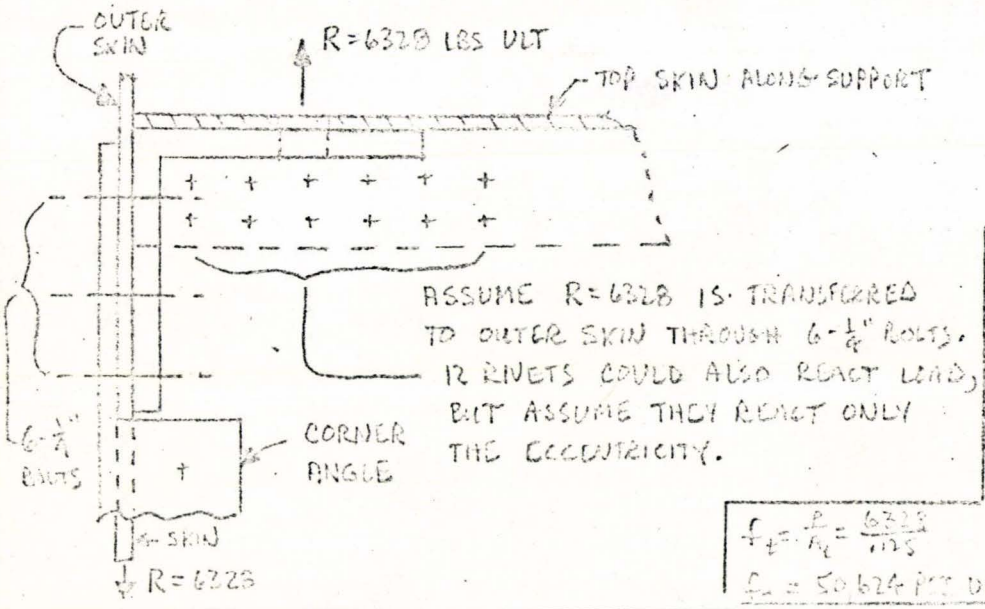
$$\underline{F_{CRIT} = 3581 \text{ PSI}} \quad ✓$$

FIND SHEAR STRESS DUE TO SHEAR FLOW

$f_s = q/t = 176/.063$

$\underline{f_s = 2794 \text{ PSI ULT}}$ ✓ ⟶ M.S. $= \frac{3581}{2794} - 1$

$\underline{M.S. = +.28}$ ✓


OUTER SKIN
R = 6328 LBS ULT
TOP SKIN ALONG SUPPORT
ASSUME R = 6328 IS TRANSFERRED TO OUTER SKIN THROUGH 6-½" BOLTS. 12 RIVETS COULD ALSO REACT LOAD, BUT ASSUME THEY REACT ONLY THE ECCENTRICITY.
6-½" BOLTS
CORNER ANGLE
SKIN
R = 6328

BEARING STRESS IN OUTER SKIN

6061-T6 ⇒ $F_{BRU} = 90{,}000$ PSI

$f_{BR} = \frac{R}{A_{BR}} = \frac{6328}{6\pi(.125)(.063)} = \underline{64{,}902 \text{ PSI ULT}}$

M.S. $= \frac{90{,}000}{64{,}902} - 1 \Rightarrow \underline{M.S. = +.38}$

SHEAR STRESS IN 6-½" BOLTS

$f_s = \frac{P}{A_S} = \frac{6328}{6\pi(.125)^2} = \underline{21{,}685 \text{ PSI ULT}}$

M.S. $= \frac{75{,}000}{21{,}685} - 1 \Rightarrow \underline{M.S. = +2.5}$

TENSILE STRESS IN ½" ATTACH BOLTS

$F_{TU} = 160{,}000$ PSI

$f_t = \frac{P}{A_t} = \frac{6328}{.175}$

$\underline{f_t = 50{,}624 \text{ PSI ULT}}$

M.S. $= \frac{160{,}000}{50{,}624} - 1$

$\underline{M.S. = +2.1}$ ✓

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ANALYSIS OF ATTACH POINTS AT END BULKHEADS FOR CONFIG. D

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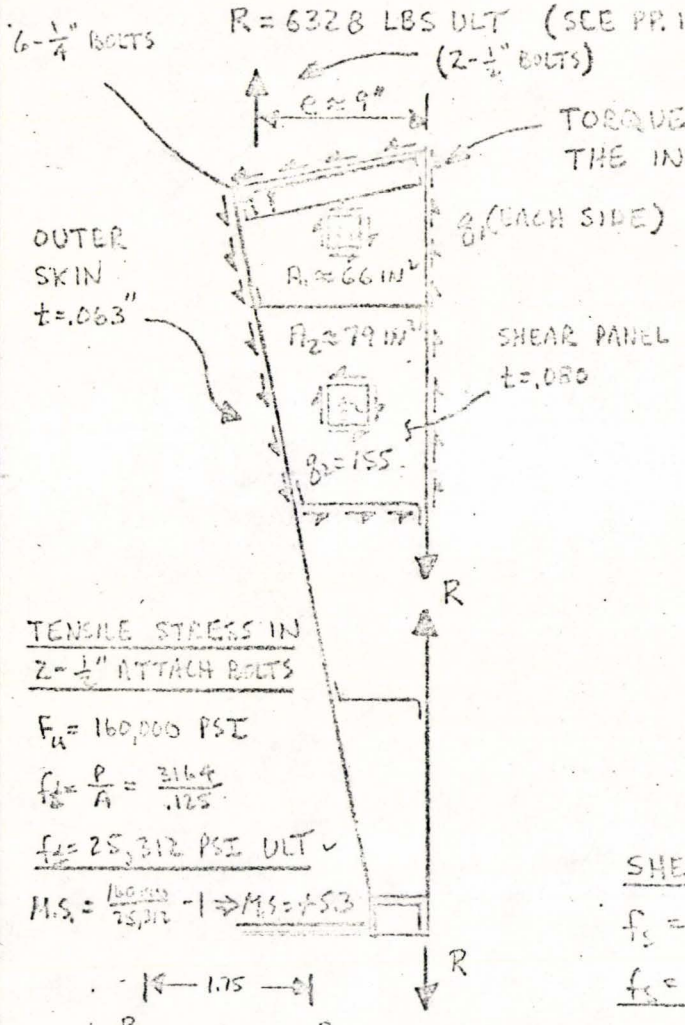
MATERIAL: ALUM

OUTER SKIN → 6061-T6 → E = 10^7
"T" CLIP → 7075-T6 → F_tu = 75,000
SHEAR PANEL → 7075-T6 → F_su = 42,000



T = TORQUE TO EACH SUPPORT

$= \frac{1}{2}Re = \frac{1}{2}\,6328 \times 9$

T = 28,476 IN-LBS ULT ✓

q_1 = SHEAR FLOW ON EACH SIDE

$= \frac{T}{2A} = \frac{28,476}{2(66+79)}$

q_1 = 98.2 LBS/IN ULT ✓

F_{CRIT} = BUCKLING STRESS (BRUHN)

$= \frac{\pi^2 k_c E}{12(1-\nu^2)}\left(\frac{t}{b}\right)^2 = \frac{\pi^2 6 (10^7)}{12(1-.3^2)}\left(\frac{.063}{10}\right)^2$

F_{CRIT} = 2152 PSI ✓ (FOR OUTER SKIN)

TENSILE STRESS IN 2-1/4" ATTACH BOLTS

F_{tu} = 160,000 PSI

$f_t = \frac{P}{A} = \frac{3164}{.125}$

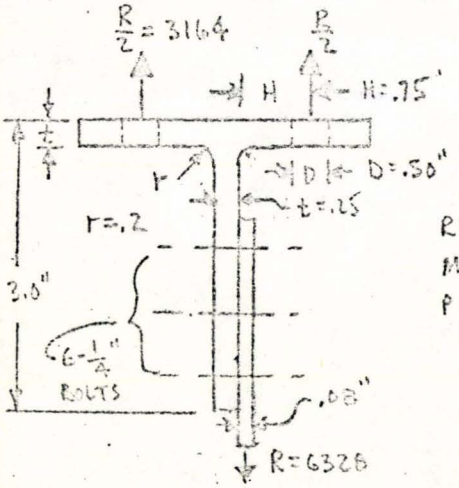
f_t = 25,312 PSI ULT ✓

$M.S. = \frac{160,000}{25,312} - 1 \Rightarrow M.S. = +.53$

SHEAR STRESS IN OUTER SKIN

$f_s = q_1/t = 98.2/.063$

f_s = 1559 PSI ULT ✓ ⟶ $M.S. = \frac{2152}{1559} - 1$ ⟶ M.S. = +.38



ULTIMATE STRENGTH OF "T" CLIP, P_u

REF: MAC 339 P 12.02.02

$\frac{t}{D} = \frac{.25}{.50} = .5$

$\frac{t}{H - \frac{t}{2} - \frac{r}{2}} = \frac{.25}{.75 - .10 - .25} = .625$

$\frac{t}{r} = \frac{.25}{.2} = 1.25$

$\Rightarrow \frac{P_u}{D^2} = 90,000$

$P_u = 90,000\,D^2 = 90,000(.5)^2$

P_u = 22,500 LBS ⟶ $M.S. = \frac{22500}{6328} - 1$ ⟶ M.S. = +2.5

R = 6328 IS REACTED BY 6-1/4" BOLTS

{SHEAR STRESS IN 1/4" BOLTS} $f_s = R/A_s = 6328/6\pi(.125)^2$ = 21,475 PSI ULT. $M.S. = \frac{75,000}{21,475} - 1 \Rightarrow M.S. = +2.5$ ✓

{BEARING STRESS} $f_{br} = P/A_{br} = \frac{6328}{2 \times .25 \times .50}$ = 52,733 PSI

$M.S. = \frac{160,000}{52,733} - 1 \Rightarrow M.S. = +1.03$

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ANALYSIS OF ATTACH POINTS AT CENTER PARTITION FOR COND D

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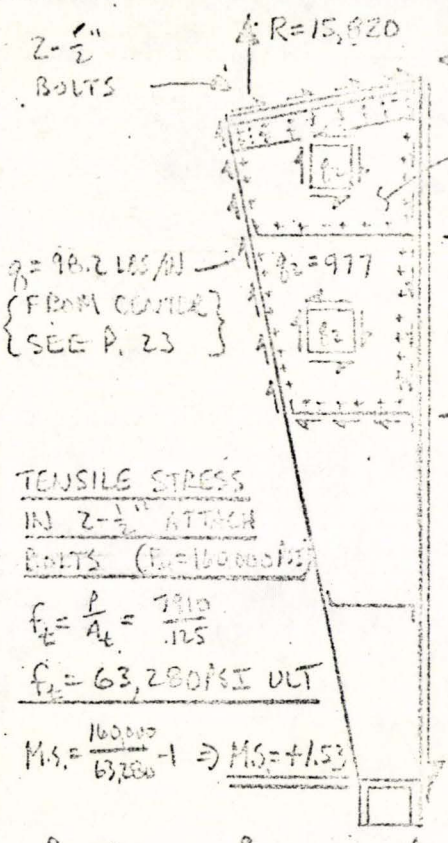


ANALYSIS OF JOINTS FOR HORIZONTAL LOADS IS SHOWN ON P. 25

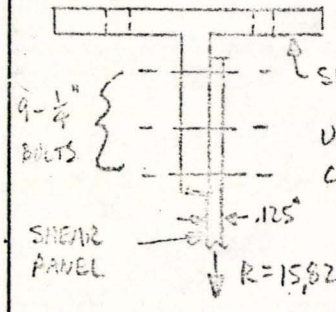
TENSILE STRESS IN 2-½" ATTACH BOLTS (F_{tu}=160,000 PSI)

$f_t = \frac{P}{A_t} = \frac{7910}{.125}$

f_t = 63,280 PSI ULT

$M.S. = \frac{160{,}000}{63{,}280} - 1 \Rightarrow M.S. = +1.53$

$\frac{P}{2}$=7910 $\frac{P}{2}$



$M.S. = \frac{22{,}500}{15{,}820} - 1$

M.S. = +.42 ✓

SHEAR IN 9-¼" BOLTS (F_s = 75,000 PSI)

$f_s = \frac{P}{A_s} = \frac{15{,}820}{9\pi(.125)^2}$ $M.S. = \frac{75{,}000}{35{,}809} - 1$

f_s = 35,809 PSI ULT ✓ → M.S. = +1.09 ✓

BEARING IN SHEAR PANEL (F_{bru} = 90,000 PSI)

$f_{brU} = \frac{P}{A_{br}} = \frac{15{,}820}{9 \times .125 \times .125}$ $M.S. = \frac{90{,}000}{56{,}249} - 1$

f_{brU} = 56,249 PSI ULT ✓ → M.S. = +.59 ✓

$R = 1.125 \times \frac{\Sigma}{32}(90{,}000)$ (SEE PP. 14, 20 & 23)

R = 15,820 LBS ULT ✓

FIND SHEAR FLOW, q_2

$q_2 = \frac{15{,}820}{10"} + q = 879 + 98.2$

q_2 = 977 LBS/IN ULT ✓

STRESS IN SHEAR PANEL (6061-T6)

$F_{CRIT} = \frac{\pi^2 k_s E}{12(1-\nu^2)}\left(\frac{t}{b}\right)^2 = \frac{\pi^2 10(10^6)}{12(1-.3^2)}\left(\frac{.125}{10}\right)^2$

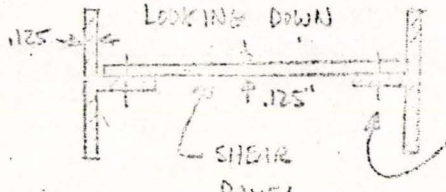
F_{CRIT} = 14,132 PSI ✓

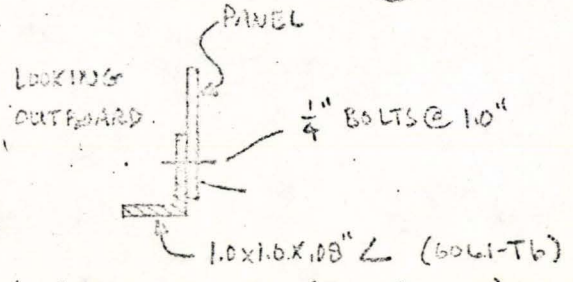
$f_s = \frac{q_2}{t} = \frac{977}{.125}$ $M.S. = \frac{14{,}132}{7816} - 1$

f_s = 7816 PSI ULT → M.S. = +.81

CHECK FASTENERS AROUND SHEAR PANEL

¼" BOLTS @ 1.0" SPACING ⇒ 977 #/BOLT





SHEAR IN BOLTS (F_s = 75,000 PSI)

$f_s = \frac{P}{A_s} = \frac{977}{\pi(.125)^2}$ $M.S. = \frac{75{,}000}{19{,}903} - 1$

f_s = 19,903 PSI ULT ✓ → M.S. = +2.8

BEARING IN ANGLE (F_{bru} = 90,000 PSI)

$f_{bru} = \frac{P}{A_{br}} = \frac{977}{.25 \times .08}$ $M.S. = \frac{90{,}000}{48{,}850} - 1$

f_{bru} = 48,850 PSI ULT ✓ → M.S. = +.84 ✓

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ANALYSIS OF ATTACH POINTS AT INTERMEDIATE BULKHEADS FOR COND D

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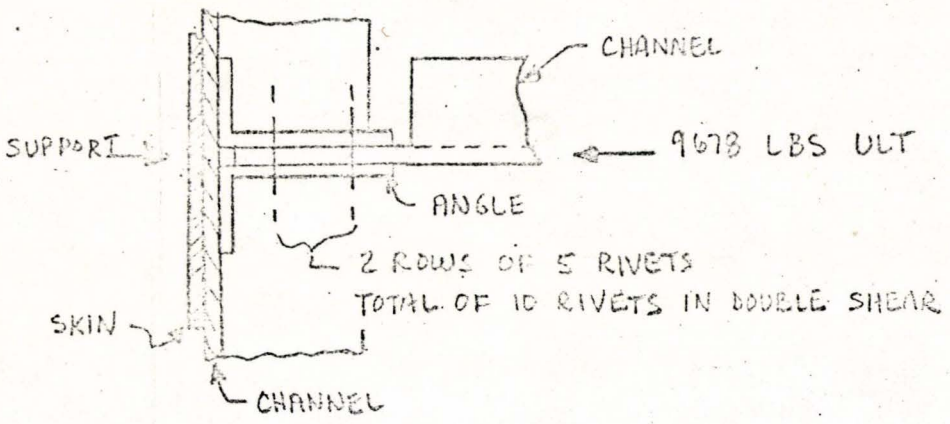
ANALYSIS OF JOINT A (SEE P. 24)

RIVETS - AD/5 (D=5/32)

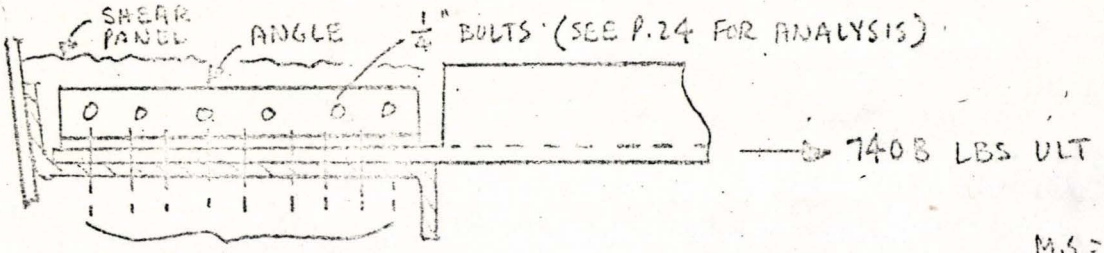
SHEAR STRENGTH = 596 LBS



$M.S. = \frac{2 \times 10 \times 596}{9678} - 1$

$M.S. = +.23$

ANALYSIS OF JOINT B (SEE P. 24)



$M.S. = \frac{18 \times 596}{7408} - 1$

$M.S. = +.45$

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ANALYSIS OF ATTACH POINTS AT INTERMEDIATE BULKHEADS FOR COND D

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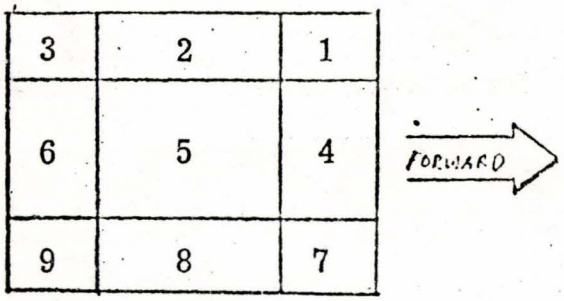
APPENDIX II

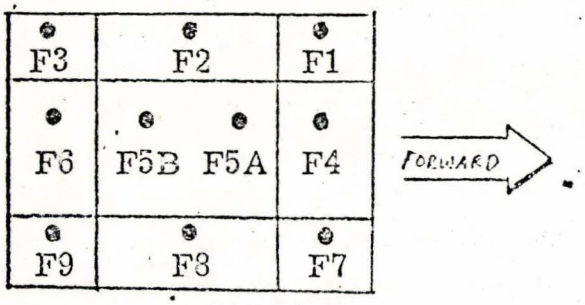
HONEYWELL FLIGHT TEST MATRIX

DESIGNATIONS

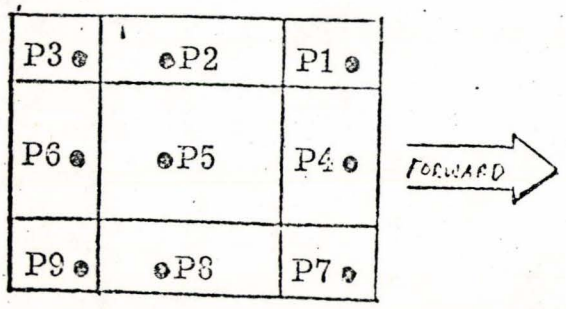


Compartment Designations

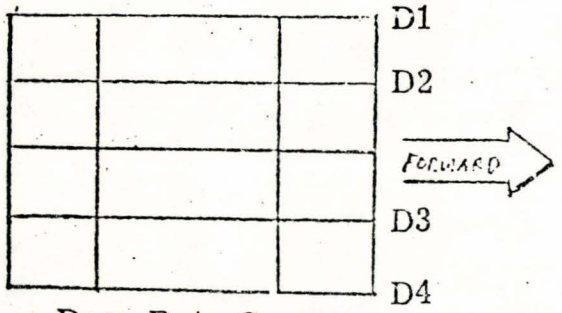
There are 23 instrument channels in the tank plus one time channel and an accelerometer channel for a maximum of 25 channels. Tank compartments are similar (essentially identical) in those elements that effect flow-rate. Thus flow rates should be identical in all tanks similarly dropped. Fourteen channels are adequate to provide data and confirmation on all configurations to be dropped.



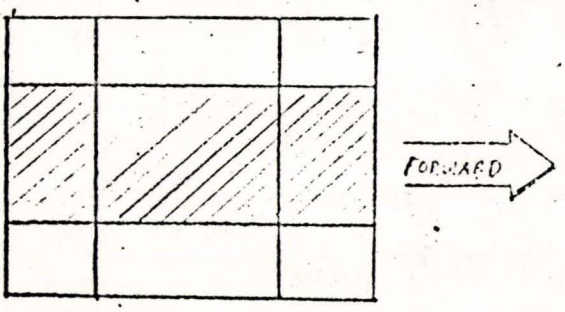
Float Gauge Designations



Pressure Gauge Designations



Door Rate Gauge Designations



1000 Basic Drop

This is the calibration volume, i.e., standard tank. It is used in a series of tests to determine aircraft velocity, drop height, and retardant characteristics. These tests are conducted with a fast door rate.

Instrumentation Channels

1 - time

1 - accelerometer

4 - float (F4, F5A, F5B, F6)

3 - Pressure (P4, P5, P6)

2 - Door (D2, D3)

Total 11 data channels.

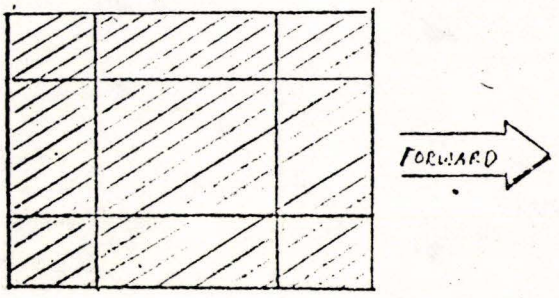
BASIC SERIES I

	Drop Height	A/C Vel.	Door Rate
Test I-1	150'	125 knots	Fast ~.2 sec.
Test I-2	300'	↓	↓
Test I-3	500'	↓	↓
Test I-4	700'	↓	↓
Test I-5	1000'	↓	↓
Test I-6	150'	Low ~100 kts	↓
Test I-7	300'	↓	↓
Test I-8	150'	High ~165 kts	↓
Test I-9	300'	↓	↓

NOTE: Basic Series I may be replicated in part or in total to explore Rheological Hypotheses, i.e., Phoschek, Firetrol 100, Water for a total of 27 tests. Allow 30 tests for possible missed data. Replicate basic test I-1, I-2, I-3, if not expended. This is the region of most interest.

	Drop Height	A/C Vel.	Door Rate
Test II-1	150	125 knots	.7 sec.
Test II-2	300	↓	↓
Test II-3	150	↓	1.4 sec.
Test II-4	300	↓	↓

NOTE: Accomplished with Baseline Retardant, PX. Need for replication with other Retardants, not clear. 4 Tests.



2000 gal. Drop

This drop is used in limited tests to identify the effect of upper quantities on pattern formation parameters.

	Drop Height	A/C Vel.	Door Rate (fast)
Test III-1	150'	125 knots	~.2
Test III-2	300'	↓	~.2
Test III-3	500'	↓	~.2

Data Channels

1 - time

1 - Acceleration

3 - Pressure (P2, P5, P8)

5 - Float (F2, F3, F5A, F6, F8)

4 - Door (D1, D2, D3, D4)

Total 14 channels.

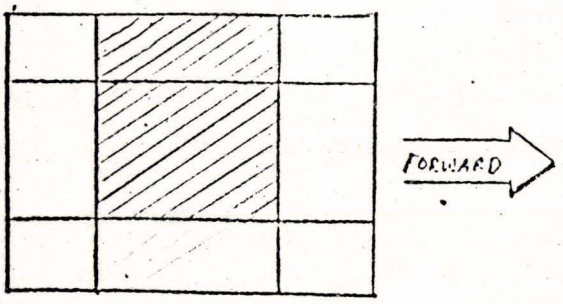
NOTE: Data represents 1 pressure and 1 float channel from each tank plus a check on each similar compartment. Supplements repeatability from static tests.

All tests with Baseline Retardant

NOTE: Unless Rheological Property differences are amplified by quantity no replications with other retardants are believed necessary.

	Drop Height	A/C Vel.	Sequence	Door Rate
* Test III-4	300	125 knots	a	~.2
Test III-5	↓	↓	b	↓
Test III-6	↓	↓	c	↓

Optional Series to evaluate method of computing trail sequence. Sequences to be determined after predictions based on static flow tests. Times to bracket predicted optimum.



1000 gallons (Short L/D)

This configuration is used in a limited number of tests and forms part of the test matrix on exit geometry.

	Drop Height	A/C Vel.	Door Rate
Test IV-1	300'	125 knots	~.2
Test IV-2	500'	↓	↓
Test IV-3	150'		

Data Channels

1 - time

1 - accelerometer

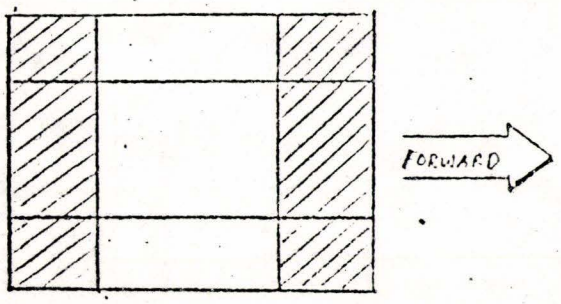
3 - Pressure (P2, P5, P8)

4 - Float (F2, F5A, F5B, F8)

4 - Door (D1, D2, D3, D4)

Total 13 Data Channels

It is estimated this release condition will produce a shorter trajectory than Baseline (Tests I-2, I-3) by about 100 feet, with differing break-up products and completeness. If ground measurements can collect breakup products (Shock Hydro) an additional drop at 150' should be considered. A separate Rheological Series might be considered.



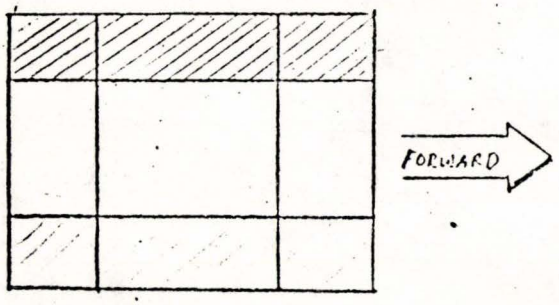
1000 gallons longitudinally separated

Used in limited tests to assess the effects of tank separation along the aircraft flight path.

Data Channels		Drop Ht.	A/C. Vel.	Door Rate
1 - Time	Test V-1	150'	125 knots	~.2
3 - Pressure (P1, P4, P9)	Test V-2	300'	↓	↓
6 - Float(F1, F3, F4, F6, F7, F9)				
4 - Door (D1, D2, D3, D4)				
Total 14 Data Channels				

All tests with baseline retardant.

NOTE: Provides float data on all compartments, pressure for each separately released door compartment.



1000 gallons vertically separated

Used to assess the effects of tank separation across flight path.

Data Channels		Drop Ht.	A/C Vel.	Door Rate
	Test VI-1	150'	125 knots	~.2
	Test VI-2	300'	↓	↓

1 - time

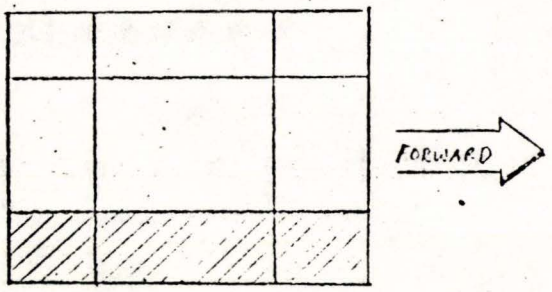
5 - Pressure (P1, P2, P3, P7, P8)

6 - Float (F1, F2, F3, F7, F8, F9)

2 - Door (D1, D4)

Total 14 Data Channels

All tests with Baseline Retardant



500 gallon Drop

This is the 500 gallon drop with long L/D used in the test matrix. It is used in a limited number of drops and always employs the fast door option.

Data Channels

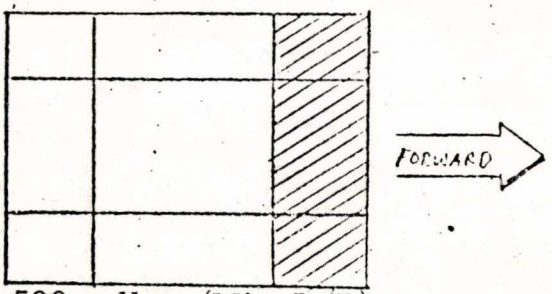
1 - time
1 - accelerometer
3 - Pressure (P7, P8, P9)
3 - Float (F7, F8, F9)
1 - Door (D4)

Total 9 Data Channels

	Drop Ht.	A/C Vel.	Door Rate
Test VII-1	150'	125 knots	~.2
Test VII-2	300'	↓	↓

All tests with Standard Retardant

NOTE: This test series with VIII, IX, and X is the most thorough exploration of exit geometry. It is probable that a replication of these tests with rheological types PX, FT, Water is rewarding.



500 gallons (Min. L/D)

This test configuration is used to determine the effect of a short tank on breakup and trajectory.

Data Channels

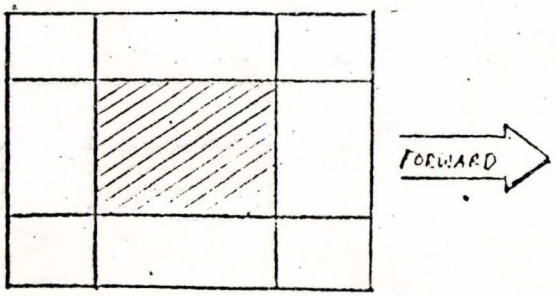
1 - time
1 - acceleration
3 - Pressure (P1, P4, P7)
3 - Float (F1, F4, F7)
4 - Door (D1, D2, D3, D4)

Total 12 Data Channels

	Drop Ht.	A/C Vel.	Door Rate
Test VIII-1	150'	125 knots	~.2
Test VIII-2	300'	↓	↓

All tests with Standard Retardant

(See Note Test VII)



500 gallon moderate L/D

This configuration is used for the basic 500 gallon (moderate L/D) drop.

Data Channels

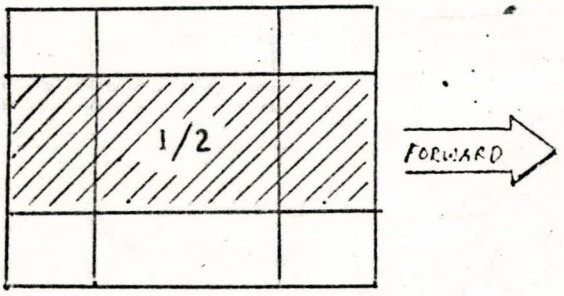
1 - time
1 - acceleration
1 - Pressure (P5)
2 - Float (F5A, F5B)
2 - Door (D2, D3)

Total 7 data channels

	Drop Ht.	A/C Vel.	Door Rate
Test IX-1	150'	125 knots	~.2
Test IX-2	300	↓	↓

All tests with Standard Retardant

Test X-1 150' 125 knots
Test X-2 300' 125 knots



This configuration is used to evaluate both the effect of head on release (viz. Down loading) and as a part of the 500 gallon perturbation study.

500 gallon short head

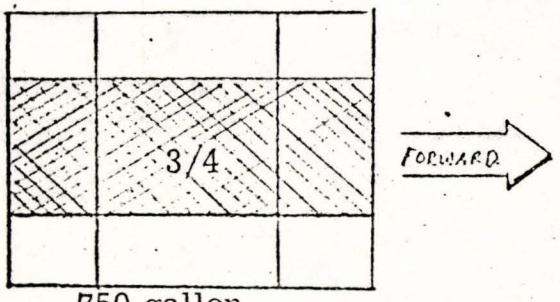
Data Channels		Drop Ht.	A/C Vel.	Door Rate
1 - time	Test X-1	150'	125 knots	~.2
1 - Acceleration	Test X-2	300'	↓	↓
3 - Pressure (P4, P5, P6)				
4 - Float (F4, F5A, F5B, F6)				
2 - Door (D2, D3)				

Door Rate: Fast ~.2 seconds

Drops: 2

Altitude: 150' and 300'

A/C Velocity: 125 knots.



750 gallon

This tank is used to develop matrix data elements on a 750 gallon drop as part of the head reduction analysis.

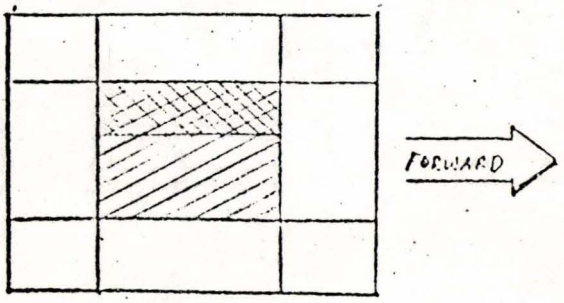
Data Channels		Drop Ht	A/C Vel.	Door Rate
1 - time	Test X-3	150'	125 knots	~.2
1 - acceleration	Test X-4	300'	↓	↓
3 - Pressure (P4, P5, P6)				
4 - Float (F4, F5A, F5B, F6)				
2 - Door (D2, D3)				

Door Rate: Fast ~.2 second

Drops: 2

Altitude: 150 and 300 feet

A/C Velocity: 125 knots



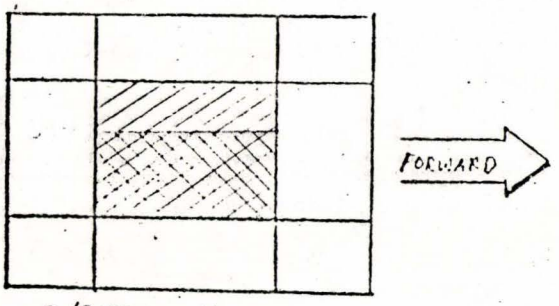
1/3 Door Area

This configuration is used to assess the effect of door exit area on pattern performance, and in a second set of tests to evaluate the increase of flow-rate via pressurization.

Data Channels

1 - time
1 - acceleration
3 - Pressure (P4, P5, P6)
4 - Float (F4, F5A, F5B, F6)
2 - Door (D2, D3)

	Drop Ht.	A/C Vel.	Door Rate
Test XI-1	150'	125 knots	~.02
Test XI-2	300'		
Test XI-3	150'		Dual*
Test XI-4	300'		



2/3 Door Area

This configuration is used to assess door exit area effects on flow and resulting pattern.

Data Channels

		Drop Ht.	A/C Vel.	Door Rate
1 - time	Test XII-1	150'	125 knots	~.2
1 - acceleration	Test XII-2	300'	↓	↓
3 - Pressure (P4, P5, P6)	Test XII-3	150'		Dual
4 - Float (F4, F5A, F5B, F6)	Test XII-4	300'	↓	↓

2 - Door ~~(D1, D2)~~
(D2, D3)